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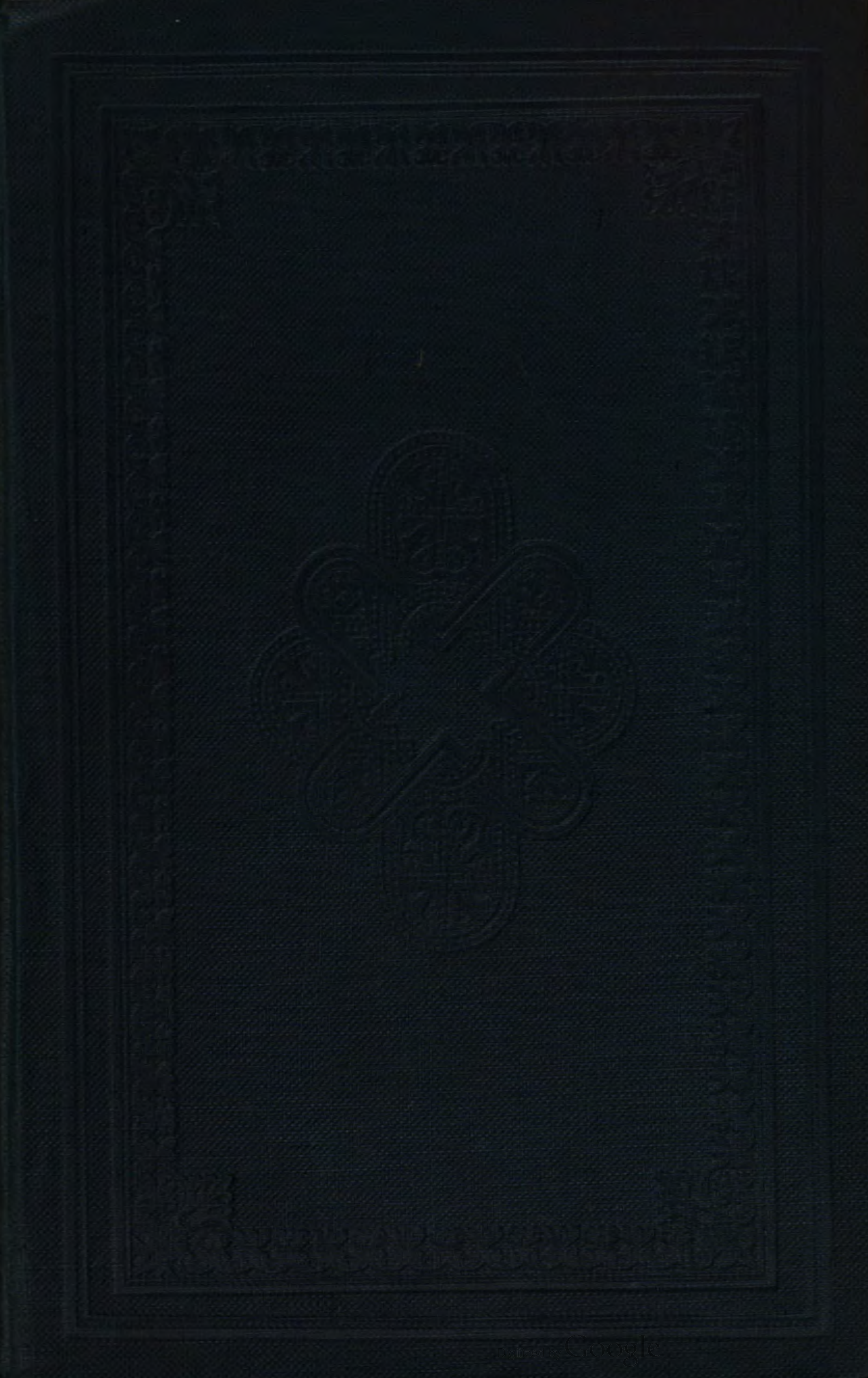

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MINUTES OF PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS;

WITH ABSTRACTS OF THE DISCUSSIONS.

VOL. XXXIII.

SESSION 1871-72.—PART I.

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ERRATA.

Vol. xxx., p. 290, line 4, *for* Y = "1·194," *read* "0·844."
" " 6, *for* Z = "0·597," " "1·194."

Vol. xxxi., p. 220. The communication presented by Mr. John Harris to the Institution was descriptive of a stone bridge on the Middlesbrough railway, and not, as stated, of a bridge across the Wear, near Witton.

" p. 234. The Gabo Island lighthouse, said to have been designed and executed by Mr. Weaver, was built while Mr. Blackett was head of the department, from the designs and under the superintendence of Mr. Alex. Beazeley, M. Inst. C.E.

Vol. xxxii., p. 287, col. 3, series 4 to 1, *for* "9·79," *read* "8·79."
" p. 322, col. 2, *for* "162," " "102."

Vol. xxxiii., p. 136, line 6, *for* "*h k*." *read* "K *k*."
" " lines 12 and 16. *for* "L *l*," *read* "T *t*."

THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1871-72.

November 14, 1871.

CHARLES B. VIGNOLES, F.R.S., President, in the Chair.

No. 1,309.—"Pneumatic Despatch Tubes: the Circuit System."[1]

By CARL SIEMENS, M. Inst. C.E.

SOON after the introduction of the electric telegraph, it was found necessary in large towns to establish branch telegraph stations, in order to facilitate the collection of messages to be sent to, and the distribution of messages received from, the central station.

Communication, between the branch and the central stations, was originally kept up either by messengers or by telegraph wires; but neither of these means was found perfectly satisfactory, for the messengers proved too slow, and re-telegraphing the messages added another chance of their suffering from mutilation; and when an unusually large number of messages had accumulated, great delay occurred in their transmission, unless several clerks and instruments were kept in readiness, which, for the greater part of their time, were not required.

It was natural that, in a city of such great commercial activity as London, the necessity of having effective communication between its central and branch telegraph stations should be soonest felt; and, consequently, it was in London that the first pneumatic system for the conveyance of telegraphic messages was established.

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[1] The discussion upon this Paper occupied portions of three evenings, but an abstract of the whole is given consecutively.

This was done by the Electric and International Telegraph Company, who connected their central station in Telegraph Street with their nearest branch stations in the City, by means of pneumatic tubes, through which carriers containing messages were forced in one direction by compressed air, and in the other by the air of the atmosphere flowing through the tubes into an exhausted receiver. This system of tubes, which was designed and carried out by Mr. Latimer Clark, M. Inst. C.E., and Mr. Varley, M. Inst. C.E., still exists, and has indeed been considerably extended since the telegraphs have passed into the hands of the Post Office authorities. It is worked by means of a steam-engine, placed in the basement of the central station, which is constantly pumping air into one receiver, which constitutes the compression chamber, and out of another, which constitutes the vacuum chamber. One end of each of the tubes, connecting the central station with a branch station, can be brought, by means of valves of a more or less complicated construction, into connection with either the compression or the vacuum chamber, and carriers can therefore be either blown to, or sucked from, a branch station through the tubes as may be desired.

This system has comparatively a very limited power of despatching messages, except for short lengths; as it is necessary to wait till a carrier has completed the whole of its journey, in one direction, through the tube before another can be sent in the other direction, and it does not admit of intermediate stations being inserted in the tubes; but every two stations must be connected by means of a separate tube.

In April, 1863, the Prussian Government applied to Messrs. Siemens and Halske, of Berlin, for propositions for establishing a system of pneumatic tubes for the despatch of messages in that city. After making numerous experiments to determine the motion of air in long tubes, which experiments will be more fully referred to further on, that firm proposed to lay tubes arranged in a circuit, and to keep a continuous current of air always flowing through them in the same direction; and they pointed out, that although it was only at first intended to connect two places, namely, the central telegraph station and the Exchange, the tubes, if laid on their system, could be afterwards extended to other places, or intermediate stations could be inserted at pleasure.

The peculiarities of this system, namely, the continuous current of air and the power of putting carriers into the tubes at any point where it is found desirable, give it great superiority, in the amount of work it is capable of doing, over previous systems.

The new project was carried out in 1865, in the following manner:—the telegraph station and the Exchange were connected by two parallel lines of drawn wrought-iron tubing 2½ inches in internal diameter, one tube being used exclusively for the passage of carriers in one direction, and the other for carriers going in the opposite direction, in a manner similar to the up and down lines of an ordinary railway. The continuous current of air for these tubes is produced by a double-acting air-pump, placed on the same bed-plate as the steam cylinder of a horizontal steam-engine erected in the basement of the telegraph station, the pistons of both the air-pump and the steam cylinders being connected by the same piston-rod. To obtain an even motion of the current of air and to neutralize the pulsation of the engine, an air-tight reservoir was placed between the ends of the two tubes and the air-pump, so that the air flows in a uniform stream from the one reservoir through the whole circuit of the tubes to the other reservoir.

After the first line had been working in Berlin for a year and a half, and had proved perfectly satisfactory in every way, the Prussian Government ordered its further extension, at first from the telegraph station to the Potsdamer Thor, with an intermediate station at the Brandenburger Thor, previous to providing the whole of Berlin with a network of pneumatic tubes, as the necessary means should become available. This second line is so arranged, that a carrier introduced at the telegraph station will, if not intercepted at either the Brandenburger Thor or the Potsdamer Thor, pass both those stations without stopping.

The total length of the pneumatic lines laid in Berlin is 32,000 feet, including the first experimental line of 5,670 feet. On account of the great length of the second circuit of tubes, they were made 3 inches in diameter inside, and to this dimension it is intended to adhere in future extensions in Berlin.

The next pneumatic system to be noticed is the one employed in Paris. The firm with which the Author is connected recommended their plan to the French Government before the Berlin line was constructed, but the French Government preferred a modified arrangement of their own. It is a circular system, but a continuous current of air is not used. Each station on the French line is provided with large air-tight vessels, which are also in communication with the water-mains of the town. By admitting water under a considerable pressure, the air in the vessels can be compressed to about two-thirds of its volume, and by means of the air so compressed the carrier or train of carriers is driven to the next station, from whence it is again driven to a further or a second station by the air which has been compressed in another set of vessels, and so on from one station to another, at stated times, round the circuit. As the air in one vessel becomes exhausted, the air in a second is brought into action, and the water in the first is run off ready for a second charge.

With any considerable traffic between the different stations the consumption of water must be enormous, because, as the air is compressed to two-thirds of its ordinary volume, for every volume of air used the expenditure of a volume and a half of water is required; or in order to send a carrier through a tube 1 mile in length and 3 inches in internal diameter, 389 cubic feet, or about 2,423 gallons of water, are required. The French line is circular, in so far as it starts from the central telegraph station in the Ministry of the Interior, passes through four stations, namely, at the Madeleine, the Grand Hôtel, the Bourse, and the Post Office, and returns to the Central Telegraph Station, so that the carriers are always sent through the tube in the same direction. The working powers of this system are of course very limited.

There is also another pneumatic line in London, which should be mentioned, although not designed for the conveyance of telegrams or single letters, but for large parcels. It is laid between Euston Station and the General Post Office, passing *viâ* Holborn, and consists of a cast-iron tube, flat on the under side, and of a D section, the tube being 4 feet high and 4½ feet wide. This line is worked by a fan 22 feet in diameter, making 150 revolutions per minute, and producing in one direction a pressure and in the other a vacuum of 10 inches of water. The length of the whole line is 2¾ miles. The average speed of a wagon is 15 miles per hour.[1]

About five years ago, Messrs. Siemens Brothers tried to induce the Post Office authorities to adopt their system of pneumatic tubes for the conveyance of letters in London; but it was only in December, 1869, when the telegraph lines were being taken over by the Government, that they received an order to lay an experimental circuit between the Central Telegraph Station and the General Post Office, St. Martin's-le-Grand. This line was completed and opened for traffic in February, 1870, and, after half a year's work, the great advantages of the system having shown themselves, a further length to Fleet Street, and subsequently to the West Strand office, Charing Cross, was decided upon.

---

[1] Fuller information, with respect to this line, will be found in a Paper read before the British Association in 1870 by Mr. Robert Sabine. *Vide* "Engineering," vol. x. p. 320. [Inst. C.E. Tract, 4to., vol. lxiii.]

Fig. 1, Plate I., is a diagram of the pneumatic tubes, laid in London on the Siemens system, but it will be observed that the arrangements differ materially from those previously adopted in Berlin.

I, II, III represent the stations at Telegraph Street, the General Post Office, and Temple Bar, and IV the station as it was proposed for Charing Cross; but the latter has been fitted with two instruments similar to the two at Telegraph Street. These two instruments were necessary, as, owing to the shape of the premises at the West Strand Office, it was found difficult to join the ends of the up and down lines with curved pipes of sufficiently large radius to allow carriers to pass from one line to the other. The ends of the up and down lines of tubing have therefore been joined by means of a bend of 6 inches radius, and an instrument has been placed on each tube.

A steam-engine, supplied by Messrs. Easton, Amos, and Co., placed in the basement of the central station, forces, by means of a double-acting air-pump, compressed air into the reservoir P, and at the same time exhausts the air from V; the reservoirs are connected with the instruments *a* and *b* by two 3-inch pipes. By means of apparatus *a*, carriers are sent to distant stations; by apparatus *b*, carriers are received.

The different stations are connected by two lines of wrought-iron tubing having an internal diameter of 3 inches; both lines are laid in the same trench, at a depth of about 12 inches below the pavement, and parallel to one another, as shown in the diagram. The tubes forming these lines are of an average length of 18 feet 8 inches. For turning round street corners, and for rising and falling in the different buildings, pieces bent to a radius of 12 feet are used. The ends of every two consecutive tubes are brought close together, and joined by means of a cast-iron 'double collar' similar to those used for joining cast-iron water-pipes, but having, in the centre of its length, an annular projection 2 inches wide, which is bored out so as to fit just over the ends of the tubes to make them butt true. A common lead and yarn joint is made at each end of the collar. Water-traps, communicating by means of slots with the bottom of the tubes, are placed at depressions on the line, to enable water, which may have got into the tubes through condensation or otherwise, dust, or other foreign matter, to be drawn off without its being necessary to take up any of the tubes.

Fig. 1 represents the circuit of tubes, in which the air is kept constantly moving in the direction of the arrows. Each of the sending and receiving instruments (Figs. 6, 7, and 8, Plate II) consists of a rocking frame with faced ends, which rocks on one of three tie-rods, E, holding together the ends of the apparatus. These ends are made of cast iron, and consist of a central boss with three arms.

Into one side of the boss is fixed a short piece of the ordinary tubing composing the circuit; the other side is faced at right angles to the axis of the tubes entering and leaving the instrument. In the faced portion of the boss, three annular grooves are turned concentric to, and surrounding, the hole forming the end of the tubing by which the carriers enter and leave the machine; these grooves have the effect of preventing the escape of air between the faced surfaces of the ends of the rocking frame and the sides of the bosses forming the ends of the machine. The three arms, springing from the central bosses of the ends, are connected together by means of three rods, E, E^{I}, and E^{II}, with nuts, by which the distance between the faced surfaces of the two bosses can be adjusted. On the lower of these rods the rocking frame turns, whilst the other two serve to limit its motion to either side.

The rocking frame of the instrument consists of two tubes, F and A′, having common flanges, *a a*, at each end, supported on two bars, D D, the lower ends of which turn on the lower rod E joining the ends of the instrument, and the upper ends of which are joined by a horizontal bar forming a handle for moving the rocking part of the instrument, so as to bring one or other of the tubes in line with the tubes forming the circuit.

One of the tubes in the rocking frame, that called the 'sending' or 'through' tube, is simply a hollow cylinder of the same internal diameter as the tubes forming the circuit. When this tube is in line with the main tubes, a carrier can pass through the instrument without being stopped, and this tube is used when it is desired to put carriers into the circuit. The other, or receiving tube A′, has a perforated diaphragm at its down stream end, so as to arrest the carriers when it is placed in line with the main tubes of the circuit. It is D-shaped in section, with a flat cover, which can be taken off if required; as for instance, to remove carriers, should two arrive at once, and so prevent the rocking frame being moved. The flat cover of the receiving tube is furnished with a pane of glass, to enable the attendant to see when a carrier has arrived.

To prevent the continuous flow of air in the whole system of tubes from being impeded, should the receiving tube be left in circuit after it has caught a carrier, which would necessarily prevent the free flow of air through the perforated diaphragm, a by-pass, G, is provided, communicating with the tubes of the circuit, A and A^{II}, on both sides of the instrument. In this by-pass there is a throttle valve, H, opened and shut by tappets on the rocking frame, in such a manner, that the throttle valve is shut when the sending or through tube of the rocking frame is in circuit, and is open when the receiving tube is in circuit. A sliding rod, held on supports, L L, and moved by the handle K, is provided for pushing the carriers out of the apparatus when intercepted.

The manipulation for sending and receiving carriers by the apparatus is exceedingly simple. To send off a carrier, the attendant has merely to push the rocking part of the apparatus from him, place the carrier in the sending or through tube, and then pull the handle towards him again, bringing the through tube into circuit, when the carrier is moved off by the current of air. To stop a carrier the action is the same; the attendant pushes the handle from him, so as to put the receiving tube in circuit; he then, as soon as the carrier arrives, pulls the handle towards him, thereby bringing the receiving tube out of circuit, and by the same motion placing the through tube in the circuit ready for through traffic. The carrier is then knocked out of the receiving tube by means of the sliding rod provided for the purpose. To make the rocking frame easier to work, the apparatus is provided with treadles, by which the attendant can move the slides with his foot.

The carriers for the reception of telegrams, letters, or light parcels, consist of small cylinders made of gutta percha, papier-maché, or tin, closed at one end, and with a lid at the other; they are covered with felt, drugget, or leather. The front ends of the carriers are provided with a thick disc of drugget or leather, fitting the tubes loosely, and the opposite ends are surrounded with a piece of drugget or leather attached to them like the leather of an ordinary lifting-pump, and fitting into the tubes in the same manner as a pump-leather fits into the barrel of a pump, but not so closely, as a good fit is not found necessary.

If such a carrier is placed in the circuit by means of the switch *a*, Station I, Fig. 1, it will be carried by the current of air in the direction of the arrows, and will pass through *a* Station II, *a* Station III, Station IV, and back through *b* Station III, *b* Station II, to *b* Station I, where it is intercepted. In like manner, if a carrier is put into the circuit at any one of the intermediate stations, it will traverse the whole length of the line between the station where it is put in and station I, and be caught by *b* Station I, unless the receiving tube of the apparatus at some intervening station is switched into the circuit to intercept it. The working of the line is controlled by electric signals, the station wishing to send a carrier signalling the letter or letters representing the station for which the carrier is intended.

Mr. Culley, M. Inst. C.E., chief engineer of the Post Office Telegraphs, has adopted the block system, such as is used on railways, for the existing circular line, and employs instruments introduced by Mr. Tyer, Assoc. Inst. C.E., for making the signals. To enable the attendant to know when a carrier has passed his station through the ' through ' tube of his instrument, Mr. Culley has had a small lever arranged in the tube, which is raised by the passing carrier, and strikes a bell.

The use of the block system prevents the tubes being able to develop their full working powers which would be obtained by sending carriers one after another, at half-minute or shorter intervals—a mode of working which could be easily carried out if a constant current of air could be depended upon, as is the case when the circular system is worked independently of other systems, which is not yet the practice in the metropolis. The working power of tubes, arranged on the circular system, is practically only limited by the power of the attendants to put carriers in and take them out of the circuit without confusion.

The length of line now working in London is as follows:—From the instrument room, situated on the third floor of the Central Telegraph Station, Telegraph Street, to the General Post Office, St. Martin's-le-Grand, 852 yards. From St. Martin's-le-Grand to the Telegraph Office in Fleet Street, near Temple Bar, 1,206 yards. From the Fleet Street Office to the West Strand Office, near Charing Cross, 1,387 yards. The circuit consists of two tubes, forming up and down lines; the total length of the circuit from Telegraph Street to the West Strand Office and back is therefore 6,890 yards.

Several experiments were made, before the last section was completed, to find out the time occupied by carriers in traversing the two sections then in use. The mean pressure during the experiments was 7 lbs. per square inch at one end of the circuit, and the vacuum at the other end of the circuit was 11 inches of mercury; under these conditions, the tubes being worked with both pressure and vacuum, the times were :—

			m.	s.
Telegraph Street to General Post Office.	852	yards	1	54
General Post Office to Temple Bar	1,206	„	2	28
Temple Bar to General Post Office	1,206	„	2	10
General Post Office to Telegraph Street.	852	„	1	13
Totals	4,116	„	7	45

With the circuit working with vacuum only, the vacuum averaging 14·25 inches of mercury at one end, the other end, or what was the pressure end before, being left open to the atmosphere, the times were:—

			m.	s.
Telegraph Street to General Post Office.	852	yards	2	48
General Post Office to Temple Bar	1,206	„	3	25
Temple Bar to General Post Office	1,206	„	2	43
General Post Office to Telegraph Street.	852	„	1	27
Totals	4,116	„	10	23

The total circuit of 4,116 yards was then worked on the old system, *i. e.*, the line was disconnected and both ends opened to the atmosphere, so that the air in the tubes came to rest; a carrier was then inserted at one end of the circuit, and the time taken from the moment the other end of the circuit was put into communication with the vacuum reservoir; the carrier, under these circumstances, took thirteen minutes and a half to travel the whole circuit, or nearly three minutes longer than when the circuit was worked with the same vacuum, but the column of air kept in movement; and within one minute of being twice as long as when both pressure and vacuum were used. The loss of time in the last experiment, as compared with the second experiment, is easily explained by the fact, that a great portion of the air, in the tube, had to be exhausted before sufficient vacuum was produced in the far end of the tube to set the carrier in motion.

These experiments show that the speed of the carrier is much greater as it approaches the vacuum end of the tube than at the other end; for instance, the carrier took forty-one seconds more time to go from Telegraph Street to the General Post Office than it did on the way back, showing that it travelled fastest in the lighter or more rarefied air.

The necessity of having a steam-engine with air-pumps and reservoirs is a great hindrance to the general introduction of pneumatic tubes. There is generally no space to spare in post offices for the erection of steam-engines; and, besides, the prime cost of the engine is often more considerable than that of the tubes, unless they are of great length.

This inconvenience has been successfully removed by the construction of an exhausting apparatus working by the direct action of steam upon a current of air; which exhauster will now take the place of the engine, air-pumps, and reservoirs.

Fig. 4, Plate I, represents such an exhauster in section; the pipe on the right side is connected with the steam boiler, and the pipe on the left side with one end of the pneumatic circuit. The steam issues from the nozzle, in the form of a hollow cylinder, through the annular opening *a a*, having a width of about a millimetre. The steam issuing in this form has the greatest possible surface, both inside and out, for contact with the air in the apparatus, which air is thus forced upwards in the direction of the arrows and draws the air out of the pneumatic tubes. The funnel of the apparatus increases gradually in size from a short way above the nozzle, thus giving more room for the mixed air and steam to expand, and thereby facilitating the flow of air from the pneumatic tubes.

By carefully proportioning the area of the annular steam orifice, the areas of influx and efflux, the length of the mixing chamber and the increase of the expanding column, the steam is made to exert its expanding power very effectually, and a vacuum equal to a column of 23 inches of mercury is obtained with a less expenditure of steam than would be required to work a steam-engine and pump to effect the same object.

Thus an exhauster of this description, with an annular orifice equal to 1, 2, 3, and 4 millimetres in width, was made to exhaust air from a closed receiver of 250 cubic feet capacity. The results are given in the following table. (For Table, see next page.)

The principal recommendation of the steam exhauster, besides its great simplicity and the small space it occupies, is the cheapness of its construction and maintenance, as the cost only amounts to about one-twentieth of that of an engine and pumps.

To work a circuit of pneumatic tubes, such, for instance, as that between Telegraph Street and Charing Cross, with an exhauster, it is only necessary to substitute the exhauster in place of the vacuum chamber, and to leave the other end of the line open to the atmosphere. With such an arrangement, the apparatus for sending carriers from the end station can be done away with, as the carriers have simply to be put into the open end of the tube. It has been calculated, that a carrier will take twenty-one minutes fifty-one seconds to traverse the whole line under a vacuum rep sented by 11 inches of mercury. In order to shorten the time, it would be advisable to divide the line at Charing Cross and put a second exhauster there, thus arranging the tubes as shown in Fig. 5. In this way the up and down lines would each have their own exhauster, and the boiler, which would have to be set up at Charing Cross, could be made to work other lines starting from that station. With a vacuum representing 11 inches of mercury maintained by such an exhauster, a carrier would travel, according to calculation, from Telegraph Street to Charing Cross, or *vice versâ*, in seven minutes forty-three seconds.

Time in Minutes.	Steam Section. 32 □ m/m.	Steam Section. 64 □ m/m.	Steam Section. 96 □ m/m.	Steam Section. 128 □ m/m.
	Vacuum.	Vacuum.	Vacuum.	Vacuum.
0·5	5½	6	6	5
1·0	9	10	9¼	8½
1·5	11½	12	11½	11
2·0	13	13½	13½	13
2·5	14	14½	14¾	14½
3·0	14½	15	16¼	15¾
3·5	15	15¼	16¾	16½
4·0	15½	15½	17¼	17
4·5	15⅝	15¾	17¾	17½
5·0	15¾	15⅞	18	17¾
5·5	..	16	18¼	18
6·0	..	..	18½	18¼
6·5	..	..	18⅝	18⅜
7·0	..	..	18¾	18½

An advantage which is gained by working by vacuum only, is, that condensation in the tubes, which sometimes in damp weather takes place to an inconvenient extent when working with compressed air, is avoided.

Owing to the large traffic expected on the existing line, the Post Office authorities had the tubes, composing the up and down lines, laid in the same trench, each station being supplied with two sending and receiving instruments, one placed on each tube. Where so much traffic is not expected, tubes laid on a large circuit could, at a comparatively small addition to the prime cost, be made to include many more intermediate stations. Fig. 2 represents such a circular system of tubes.

The difference in the working of the two systems will be explained by the following example. Suppose Station II. on each of the systems wishes to send a carrier to Station I.; in the case of the system shown in Fig. 1, the carrier would pass directly from the instrument *b*, on the up line at Station II. to instrument *b*, in Station I. without passing through any other stations; whereas, on the system shown by Fig. 2, a carrier put into the circuit at Station II. to be sent to Station I. would have to pass through Stations III. IV. and V. before arriving at its destination.

Fig. 3 represents an arrangement of circuits for a large town, in which the main circuits may be supposed to consist of 4-inch, and the branch circuits of 3-inch tubes. In such a system some of the intermediate stations on the main circuits become, as it were, central stations for the branch circuits, and would have to be provided with separate pumping-engines or exhausters, as the diversion of the air, circulating in the main circuits through the branches, would retard the working of the whole.

The following are the experiments that were made at Berlin, with the view of determining the rates with which carriers can be made to travel through circular pneumatic tubes.

A pump, worked by a crank and fly-wheel, which could be used for either exhausting or compressing, was arranged so as to pump air into or out of an air reservoir of several times the capacity of the cylinder of the pump. The reservoir communicated with the atmosphere by means of the tube on which the experiment was to be made. The pressure in the reservoir was measured by means of a mercury pressure-gauge.

It was now easy to keep the pump going at such a speed as to preserve the pressure or vacuum in the reservoir constant, proving that the same amount of air was being pumped into or out of the reservoir as was passing through the tube being experimented upon.

The tube terminated, at the end farthest from the reservoir, in a carefully constructed gas-meter, which indicated exactly the amount of air passing through the tube in a certain time. The quantity of air measured in a certain time by the meter, divided by the sectional area of the tube, gave the speed with which air of atmospheric density either entered the meter from the tube when the air was compressed in the reservoir, or entered the tube from the atmosphere through the meter when the air in the reservoir was rarefied. As the same amount of air must necessarily flow in the same space of time out of one end of the tube as enters it at the other, it is easy, the pressure in the reservoir being known, to calculate by means of Marriotte's law, the speed at which the air either enters or leaves the end of the tube farthest from the meter. For instance, suppose the air in the reservoir to have been exhausted by half an atmosphere, and the speed of the air at atmospheric density at the entrance of the tube to be equal to 50 feet per second; then, as the same quantity of air must enter the reservoir as enters the tube, and as it enters the reservoir at half the pressure, it will take up double the volume, and therefore its speed will be equal to 100 feet per second.

The speed at different places along the tube could also be determined by measuring the density of the air at the different places. By repeating these experiments with tubes of equal lengths and different diameters, and tubes of equal diameters and different lengths, the influence of length and diameter of the tubes on the speed of the current of air was arrived at, and the following formulæ were obtained:

I. Mean velocity $v' = \frac{v_{,} + v_{,,}}{2}$.

II. Final velocity $v_{,} = a \, . \, \frac{h - h_1}{h} \, . \, \sqrt{\frac{d}{l}}$.

III. Initial velocity $v_{,,} = a \, h_1 \left(\frac{h - h_1}{h^2} \right) . \, \sqrt{\frac{d}{l}}$.

IV. Velocity at distance x measured from the beginning of the tube:

$$v = a \, . \, \frac{(l - x) \, h_1 + x \, h}{l} \, . \, \frac{h - h_1}{h^2} \, . \, \sqrt{\frac{d}{l}}.$$

V. Mean velocity $v' = a \, . \, \frac{h^2 - h_1^2}{2 \, h^2} \, . \, \sqrt{\frac{d}{l}}$,

where l = the length of the tube,
d = its inner diameter, } Either in inches, feet, or metres.
h = the pressure of the air entering the tube,
h_1 = the pressure of the air leaving the tube,
$h - h_1$ = the effective pressure, } Either in atmospheres, lbs. per square inch, or inches of mercury.
a = a constant.

The experiments, however, proved these formulæ to be but approximately right. The mean velocity of the air increases practically faster than the square root of the diameter of the tube. This difference is probably owing to a layer of air being retained by molecular attraction on the inner surface of the tube, thereby decreasing its diameter; the fact that this occurs should be taken into consideration when the tubes to be employed are of small diameter.

The constant a given in the above formulæ, and which depends on the nature of the inner surface of the tubes, was found to equal 15950. By making use of this constant, in calculating the velocity of the air in a tube 13,000 feet long and 3 inches in diameter, with a difference of pressure of one atmosphere between the two ends, there result—

1) With one atmosphere of pressure,
   i. e. $h = 2$.
   $h_1 = 1$, a mean velocity of 26·2 feet per second.
2) With a vacuum of one atmosphere,
   i.e. $h = 1$.
   $h_1 = 0$, a mean velocity of 35 feet per second.
3) With a pressure of half an atmosphere and a vacuum of half an atmosphere,
   i.e. $h = 1\frac{1}{2}$
   $h_1 = \frac{1}{2}$, a mean velocity of 31·1 feet per second.

The foregoing prove that, in very long lines of tubes of small diameter, a sufficient velocity of the column of air can be obtained with the pressure at the two ends differing within quite practical limits. If the carrier is made so as to move with very little friction, its speed will be nearly equal to that of the column of air by itself. The momentum of the carrier, and that of the column of air, may be entirely disregarded, as both are infinitely small when compared with the prevailing friction of the air in the tube. It would be different if the carrier required any considerable force to move it, as in that case the air would become much denser behind than before the carrier, and a loss of speed would result. The requirements of each case should determine the dimensions of the tubes. As under equal conditions of pressure at the two ends, the speed in the tube increases as the square root of the diameter, and decreases as the square root of the length of the tube, the length of a pneumatic system may be extended with similar results as to speed in the same proportion as the diameter of the tubes can be increased: that is, the same speed as is obtained through a tube of a certain diameter and length may be obtained through another of double the length and double the diameter, the difference of the pressures at the two ends of the tubes remaining identical.

The value of $a = 15950$ found by these experiments is only correct for the comparatively smooth surface of lead tubes.

To find the speed of a carrier passing through the wrought-iron tubes of the pneumatic circuit in London, it is necessary to determine the value of a for these tubes. With a pressure of 7 lbs. per square inch, and a vacuum represented by 11 inches of mercury, the carrier completes the circuit from Telegraph Street to Temple Bar and back in seven minutes forty-five seconds = four hundred and sixty-five seconds. Thus—

$$v' = a \frac{h^2 - h_1^2}{2 h^2} \sqrt{\frac{d}{l}},$$

where $h = 44$, $h_1 = 19$, $l = 12{,}168$ feet, $d = \cdot 25$ of a foot: thus the value of $v' = 26 \cdot 168$, and of $a = 14192$.

Taking the above into consideration, the completion of the carrier's passage through the whole circuit, from Telegraph Street to Charing Cross and back, will take (l being 21408 feet) eighteen minutes five seconds if the same pressure and vacuum are made use of as before.

A carrier takes two hundred and sixty-two seconds to go from Telegraph Street to Temple Bar, but only two hundred and three seconds for its return. Under these circumstances, a carrier will take ten minutes eleven seconds from Telegraph Street to Charing Cross, and seven minutes fifty-four seconds only for its return to Telegraph Street.

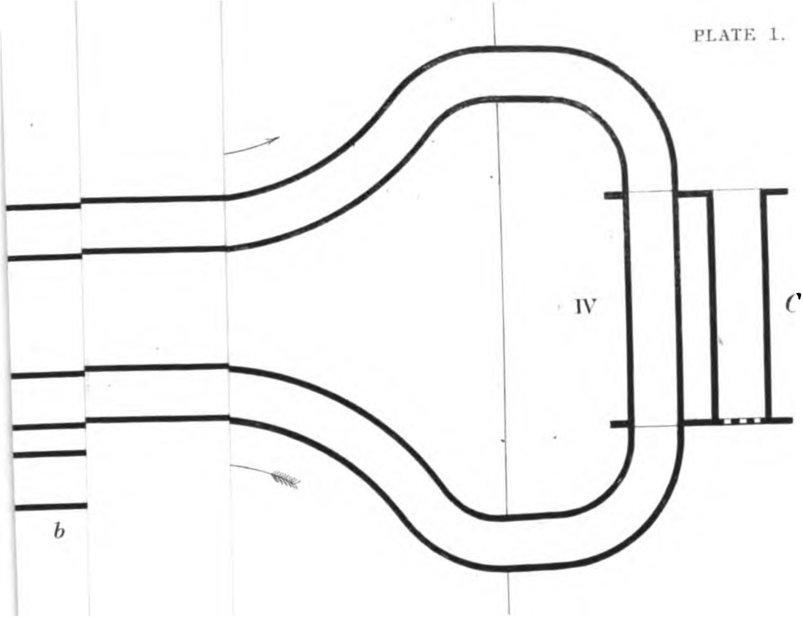
Up to the present time, as far as the public is concerned, the pneumatic tubes in London, Berlin, and Paris have only been used for the conveyance of telegraphic messages, but the British Post Office authorities have already considered the question, whether it would not be advantageous to have the letter-post service, in London, executed by means of pneumatic tubes; and as the advantages of such a mode of conveyance would undoubtedly be very great, it appears probable that, if once established, it would soon be extended, upon a comprehensive scale, as the ordinary means for the distribution of letters throughout the metropolitan districts. With such a system of distribution, an accumulation of letters at principal offices would be entirely avoided, and the actual delivery of every letter could easily be effected within an hour of the time of its being posted, at a cost certainly not exceeding that of the present arrangements for collecting, assorting, and re-distribution by means of foot carriers and postal carts.

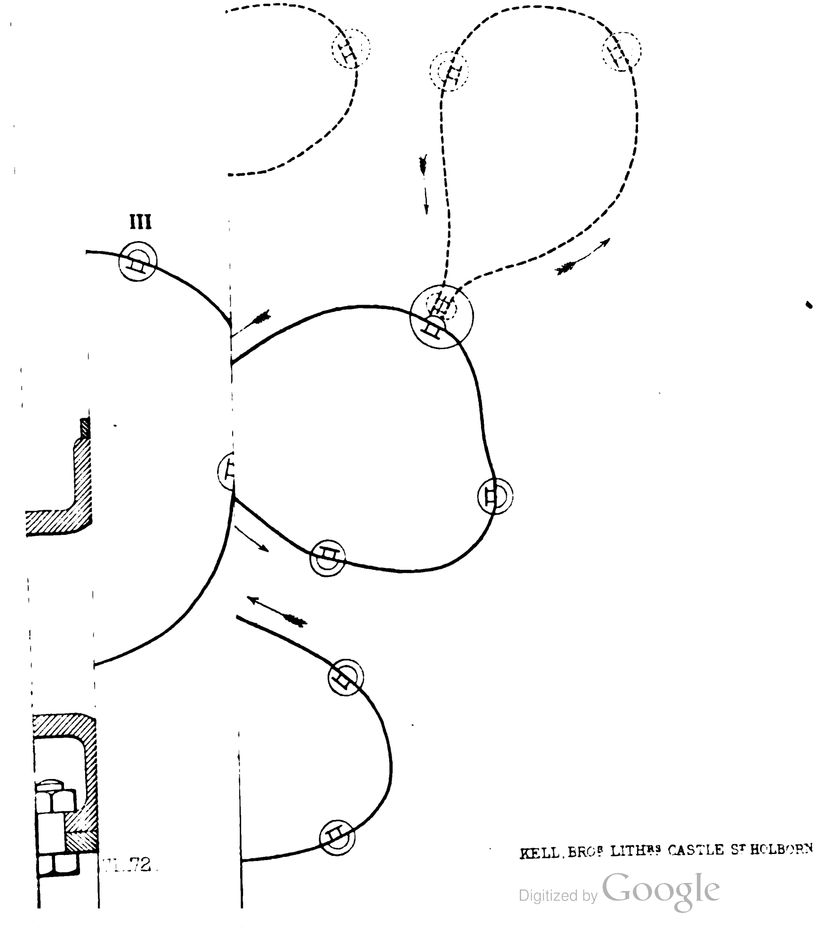
The communication is accompanied by a series of diagrams, from which Plates 1 and 2 have been compiled.

[Mr. C. W. Siemens.

Mr. C. W. **Siemens** said he would point out the leading features of this system as compared with other pneumatic systems, which had been in use for many years. In sending a carrier through a pipe on the old system, the pipe was entirely occupied by that carrier; and, if the carrier was sent back by suction in the same pipe, double the time of transit would be occupied. That was sufficient for short distances; but for greater distances the working capacity of the tube became very small, because the piston velocity of a carrier in a tube of small diameter would not exceed 1,000 or 1,200 feet per minute; therefore, in a tube several thousand feet long, the time occupied in sending a carrier and receiving one back would be considerable. Now it had occurred to his firm, that if a line could be made continuous—if instead of sending a carrier and waiting for the return carrier to be despatched through the same tube, or even another tube, in that case the carrier would form, as it were, part of the current of air rushing through the entire circuit, and any number of light carriers might follow each other without inconvenience, and largely increase the working capacity of the tube. Moreover, it occurred to his firm that, with a continuous circuit, intermediate stations might be introduced for shunting out and putting in carriers to be sent forward in the same circuit, whereby a multiplicity of tubes, otherwise necessary, would be avoided. Four or five years ago he made a proposition to the Postmaster-General to apply this system to the transmission of letters, but it had not been carried out though, probably, at a future time, the project might be seriously entertained. By such a system the despatch of letters would, unquestionably, be much accelerated, and he should be much surprised if it did not prove the cheapest mode of transit in London and other large towns. The diagrams sufficiently showed the mode of working such a system, especially Fig. 3, Plate 1, where the circuit branched out at local stations.

The only other point of interest to which he would allude was the blowing apparatus. This was now working occasionally at the Post Office in the way of trial against the engines. It was not quite equal in steam economy with the engines, but it must be borne in mind that the steam pressure was only 35 lbs. or 40 lbs., and the steam engine employed was a very good one. Comparative trials showed that, with the same boiler power, the steam engine maintained from 2 to 3 inches more vacuum with the tube open than the steam blower; but other experiments with a higher pressure of steam reversed that result. With steam of 70 lbs.

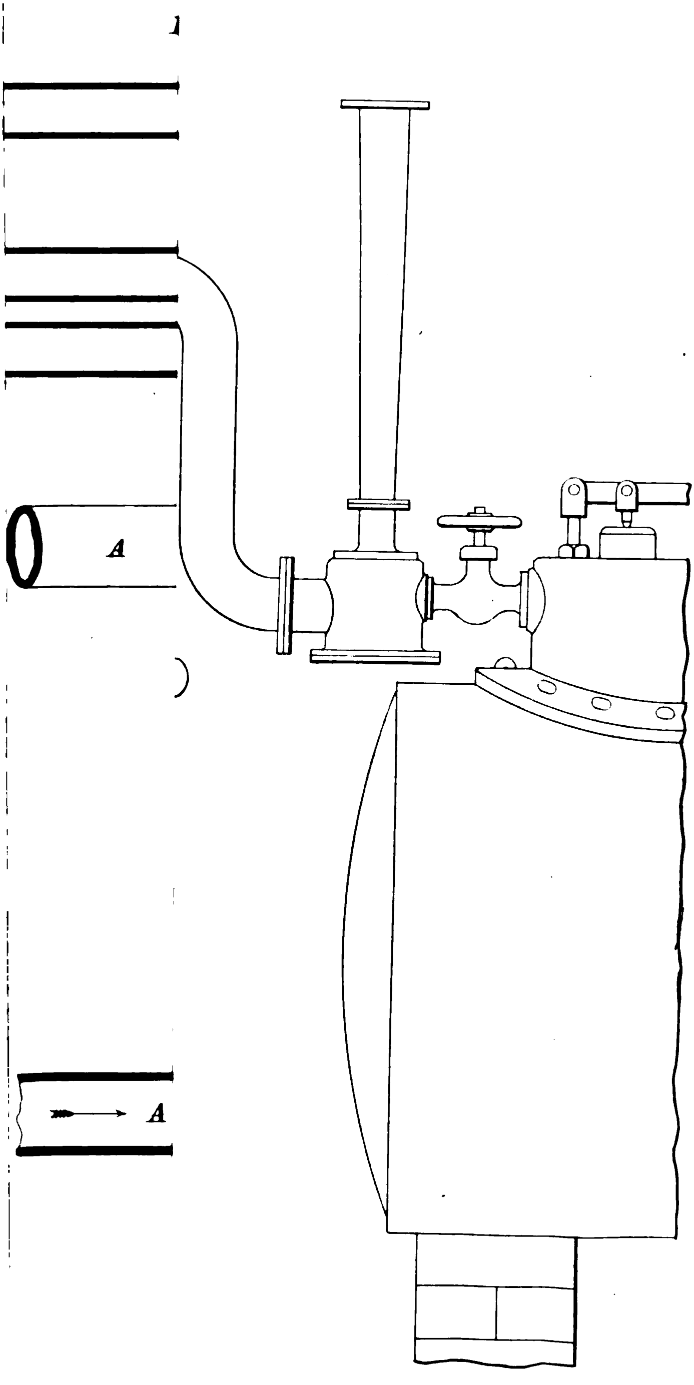




KELL. BROS LITHRS CASTLE ST HOLBORN

EUMATIC

PLATE 2.



KELL BROS LITHRS CASTLE ST HOLBORN.

pressure, the working results of the steam blower were superior to those of the steam engine.

Mr. **HAWKSHAW**, Past-President, inquired how the risk of cutting the carrier in two by the introduction of the rocking-frame was avoided, supposing it was just passing the joint at the moment the rocking frame was worked?

Mr. **SIEMENS** replied, that the attendant heard when the carrier had arrived, as it made a little noise; but a small bell might be made to sound automatically when the carrier had arrived within 20 yards of the station.

Mr. R. S. **CULLEY** stated that, before the block system was introduced, the carriers were occasionally cut in two; because, though there was plenty of room in the receiving slide for one carrier, there was not room enough for two, and sometimes a second carrier arrived when the attendants were not aware of it. They turned the slide over for the first carrier, and thus injured the other. Since the block system had been employed that had never occurred.

Mr. **BARLOW** said he had lately seen the Siemens apparatus at work in London and in Berlin, and he could testify to its great merits. In Berlin he noticed that it not only carried messages through the horizontal tubes, but also through a vertical tube from the bottom to the top floors of the Central Telegraph Office; and in London work of a like nature was carried on. In the latter case he witnessed the relative effects of the steam engine and the steam jets at the Telegraph Office. In the cellar of that building there was an engine working an air-pump, and producing the vacuum which imparted motion to the carriers. He saw the engine shut off, and then small steam jets put on, and the effect, as far as he saw, was that the vacuum was rather increased than diminished. The difference was very small, but what there was was in favour of the steam jets. He believed the experiment was not a conclusive one, as it was interfered with by some other action in the circuit, but those were the results he saw. He had made some experiments on the tube laid from Euston Square to the Post Office. It had been mentioned that the vacuum generated in that tube, with a fan 22 feet in diameter, supported a column of 10 inches of water; now although the apparent effect was so, he did not think that was a correct register of the vacuum power of the instrument. There occurred between Holborn and the Post Office a gradient of 1 in 14, and he had seen loads of 10 and 12 tons brought up that gradient; but it required a vacuum equivalent to considerably more than 10 inches of water to draw such a load up so steep a gradient;

and he mentioned the circumstance to show that it required a higher pressure than was registered to produce that result.

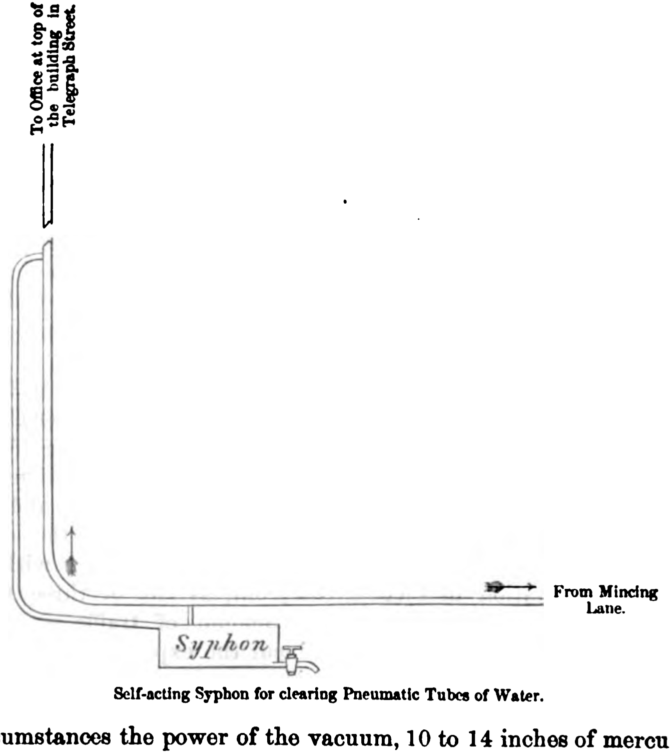
Mr. C. F. VARLEY observed that Mr. Josiah Latimer Clark, who in 1853 and 1854 was the engineer of the Electric Telegraph Company, proposed the introduction of the first pneumatic tubes used by that company, and constructed one from Founder's Court, Lothbury, to the Stock Exchange, Throgmorton Street of 1½ inch internal diameter, and about 220 yards in length. Many things were learnt from the failures which were constantly met with in the early years of the pneumatic system, the carriers or pistons often sticking half way. By Mr. Clark's plan a vacuum only was used, and carriers were sent only in one direction. Later, about the year 1858, when a pipe 2¼ inches internal diameter was extended from Telegraph Street to Mincing Lane, 1,340 yards in length, the traffic was so considerable that it was found desirable to have the power of sending messages in both directions. To effect that a smaller pipe, 1½ inch in internal diameter, was laid between Telegraph Street and Mincing Lane, with a view of carrying the vacuum to the latter station, so as to take messages in the opposite direction. This smaller pipe was found so to wiredraw the current that the pipe would not work, the leakage past the carrier being too considerable; and accordingly a large chamber was built in the basement floor or kitchen at the corner of Mincing Lane and Leadenhall Street to collect power or vacuum for bringing the messages from Telegraph Street to Mincing Lane. This chamber was constructed of timber, 14 feet by 12 feet broad, and 10 feet high, and was covered with lead. It was not strong enough to withstand the pressure; for one day a carrier having stuck half way, and when there was a higher vacuum than usual, viz., 23 inches of mercury, it collapsed with a loud report. At the time the landlord of the house happened to be dining in the next room, and he suddenly found himself, his table, dinner, and the door, which was wrenched off its hinges, precipitated into the room amongst the débris of the chamber. The windows were forced inwards, and those on the opposite side of Mincing Lane and Leadenhall Street were drawn outwards. The damage was considerable. This accident put an end for a time to the attempt to send telegraph messages by means of vacuum conveyed through this smaller pipe. About that time he became the engineer-in-chief of the Electric Telegraph Company, and got permission from the directors to introduce a new system, viz., compressed air, though many persons contended that it would be impossible to blow messages through a pipe, because all attempts to blow air through long pipes had utterly failed; while others said that, if messages were sent, they would go much slower than with the vacuum. Now, Mr. Siemens had shown that on his system messages arriving at the vacuum end of the tube travelled quicker than those going through the compressed air end of the tube. That was true of his circuit system, because if there was a pressure of two atmospheres at one end, and a pressure of one atmosphere at the other, at the one end of the tube one cubic foot of air would expand to two cubic feet at the other, and the velocity of the air at the latter end would be double what it was at the other end. In his apparatus, for he was the first to introduce compressed air, the reverse was found to be the case, and for this reason: the tube did not consume power until a message was about to be forwarded; and in a tube 1,300 yards in length, and 2¼ inches in diameter, 15 seconds elapsed before the vacuum was felt at the distant end after communication had been established with the exhausted chamber at the engine end of the tube; consequently the carrier did not start until after 15 seconds had elapsed. When a message was sent by compressed air, it was sent from the end at which the power was applied, and the carrier started at once, thus gaining a start of 15 seconds; now, inasmuch as the air in the tube had to be compressed, it started at a very high velocity, and when it reached the other end the compressed air in expanding gave it a higher velocity. The result was, in 1,340 yards from Telegraph Street to Mincing Lane, the carriers were drawn by vacuum, on an average, in from 60 to 70 seconds, and were propelled by compressed air in about 50 or 55 seconds, the difference of pressure in each case being nearly equal.

This elaborate system of Mr. Siemens for intermediate stations was one which had occupied the attention of Mr. Latimer Clark and afterwards of himself, for Mr. Clark, when engineer of the Electric and International Telegraph Company, was anxious to carry out his vacuum system between Telegraph Street and the Strand. Subsequently, when Mr. Varley introduced the compressed-air system, he sought permission to do this work with an intermediate station in Fleet Street; but, as two or three telegraph companies were at work, the amount of traffic was not sufficient to induce the directors to incur the expense of laying so long and large a tube to that station. In fact, between no two stations was there traffic sufficient to admit of the expense of the double pair of tubes: however, as each carrier would accommodate twelve to fourteen messages, a single tube was more than sufficient.

These tubes were introduced by the Electric and International Telegraph Company for purposes of economy, rather than for the saving of errors in the messages, as the economy to the company in dispensing with the large number of clerks employed to transmit the messages from the various London branch stations to the central office was very considerable; and it was found between Mincing Lane and Telegraph Street that the amount of money saved in the salaries of clerks and messengers more than paid the whole cost of working the engine, and the interest upon the outlay for pipes and engines.

The pipes, as first laid, had screwed joints, which always leaked more or less; and whenever vacuum was applied to the tube it drew in water. After a wet day there was frequently collected as much water as to give a column over 20 feet in height. As the pipes were vertical for 80 feet in the central station, under these circumstances the power of the vacuum, 10 to 14 inches of mercury, was balanced, and the carrier could not pass. That led to the

Fig. 1.



Self-acting Syphon for clearing Pneumatic Tubes of Water.

adoption of the following measure: a large chamber was connected with the bottom of the pipe, and a second pipe, communicating with the chamber, was inserted 30 feet higher up in the main pipe, Fig. 1, so that when water got in, it ran into this chamber, and allowed the carrier to pass. The screw-joints were subsequently cut out, and the pipes soldered in one length; and after that there was very little difficulty from the presence of water.

By the introduction of the system just described, he not only obtained a backward and forward transit of the messages through the pipe, but he also effected a considerable saving in the expense attending the working of the ordinary valves; for the boy, when receiving a carrier, with the original valve, had to close the upper valve, then open the cock to establish the communication with the vacuum-chamber, and to fix it open; and this, in fact, took so much time that one boy could only effectively attend to two busy pipes; but by the valve arrangement he had introduced, the compressed air and vacuum were made to do all the drudgery. The moment a carrier was announced, by electric bell, as being at the distant end, the boy touched a little button, marked receive, which opened a communication between the exhausted chamber and two small cylinders. The first cylinder closed the door of the receiving apparatus, while the second drew up the piston connected with the valve which opened the communication between the exhausted chamber and the pneumatic tube. All the boy had to do was to touch the button for half a second, and all that was required was done, viz., the receiving door closed, the vacuum communication opened, and the detent set to retain it open. As soon as the carrier arrived it struck against a piston of india-rubber, and opened a valve; that established a communication between the exhausted chamber and a third cylinder, which cut off the vacuum. The door opened by gravity, and the carrier dropped into a receptacle before the boy in attendance. If a message had to be sent the carrier containing it was placed in the pipe, and the button marked "send" was then depressed for half a second. This opened a communication between the compressed-air chamber and a small cylinder connected with a slide-valve, which instantly closed the end of the tube behind the carrier. When the piston in the small cylinder had reached its destination it passed a small tube which opened a communication with a second cylinder, the piston of which was blown down and opened the main communication between the compressed-air cylinder and the tube. The carrier and its messages were then blown to their destination. When the carrier arrived there the receiving boy rang an electric bell, to indicate its arrival, and the sending boy had simply to touch the knob of a third small valve, marked "cut off," when, in half a second, the small cylinders withdrew the detent, and so closed the compressed-air valve and withdrew the slide-valve that had closed the tube; the tube was then in a normal condition, ready to send or receive carriers. This system, as he had observed, effected considerable economy, and the working of the tubes became much more regular. The carriers which were used at first gave an immense deal of trouble. Metal carriers were unsuitable, because the collisions crushed them. Gutta-percha was found to answer best; but if, from the wearing of the felt, or otherwise, it came in contact with the tube, the high velocity generated heat sufficient to melt the gutta-percha, which adhered to the tube, and so impeded the transmission of the carriers that they would frequently stick in the pipe. He ultimately found the best thing was to cover the carrier all over with felt, after doing which a carrier seldom stuck fast. When a carrier rushed into the exhausted tube, the air in it, which was at the usual atmospheric density, suddenly expanded. He had tried various means of preventing the ill effects arising from this action, but it was so sudden that even large holes in the cap were insufficient to prevent their blowing out. At last the idea occurred to him of employing a simple broad elastic band to hold the messages in the carrier, without any cap at all, and this proved successful. The caps never got across the tube, because there were none to do so and stoppages in the pipe became of rare occurrence.

The length of tube through which it was possible to send a carrier depended upon the fit of the piston. If the piston fitted quite air-tight, and with very little friction, impossible with iron tubes, a carrier could be sent to any distance; but practically a piston would not fit. The carriers would wear, especially in the iron pipes used by Mr. Siemens, and the limit of distance was soon reached. He questioned whether a pipe 3 inches in diameter, between Charing Cross and Telegraph Street, would be sufficient for regular and accurate working, unless special attention was paid to the pistons.

He had once or twice found leaden pipes compressed, from stones getting into the over iron protecting pipe. The indentation being found out, by attaching a carrier, soaked in water to make it air-tight, to a piece of good string, it was easy to discover where the indentation existed, even at distances of over 150 yards. The water not only made the carrier leakless, and so receive the whole power of the vacuum, but it lubricated the string, and enabled the carrier to drag it around the bends in the tube for 150 yards or more. Mr. Siemens had used wrought-iron pipes between the City and the Strand. These rough pipes destroyed the carriers very fast. He had always used lead pipes in iron. Mr. Siemens was not using the 'circuit' system between the City and the Strand, because he had cut the pipe asunder at the Strand. The difference between his plan, as used in London, and Mr. Varley's, was simply this:—1. Mr. Siemens used one pipe for vacuum and one for compressed air—he used only one pipe for both 'up' and 'down' messages; 2. Mr. Siemens used a large valve difficult to manipulate—he used a small one, in which the compressed air or vacuum did the laborious part of the work.

Mr. LATIMER CLARK remarked that the system advocated in the Paper seemed to be the inevitable result of the extension of the system which he had had the good fortune to introduce in 1853. It was a more important question than appeared at first sight; and the saving effected by the tubes, in time, in money, and in errors of transmission, was larger than was supposed. There was one part of the Paper which he hailed with even greater pleasure than the improvements that had been described; and that was the announcement of the use of the steam jet for obtaining a vacuum. If it was proved that a vacuum could be effectively and economically produced by the steam jet, it would not only be found of great value for the transmission of telegraph messages, but for much larger and more important uses. Much, however, as he admired the ingenuity of this system, he was not sure that it was better than the old one; but not having had any practical experience of the new system, he could speak only from impression. The original system was in full practical operation in 1854, and when it devolved upon him, in 1858 or 1859, to propose a large scheme for connecting the Strand and other local stations with the central office, the plan he thought best was that of a series of tubes going from station to station, each furnished with a second independent tube, carrying a vacuum alongside, so that messages could be passed to and fro in every direction by the use of vacuum only, without the aid of compressed air. By providing engines at Lothbury, the Strand, Regent Circus, and Holborn, all pumping on one common reservoir, a reservoir of vacuum would be prepared and stored, which would be used only at the moment when the message was sent. He thought the advantages of this plan were great, and in his opinion they counterbalanced the advantages of the system now under consideration. In this plan there was a double set of pumps in action; one for exhaust, the other for compression; and these were sometimes working with compressed air, which had admitted disadvantages. The whole of the machinery was in incessant action, expending power whether the carriers were passing or not; and there were no facilities for establishing branch stations. It had the further disadvantage, that although nominally a great many carriers could be put into the tube, and sent away in rapid succession, yet, practically, two carriers could not be put in at once, for in that case they blocked up the receiving boxes, and the carriers were damaged in being removed. In fact, the block system became necessary, and no second carrier could be despatched until the first had arrived at the receiving station; so that he doubted whether there was really greater economy and advantage in that than in the older system. He thought the pneumatic system was as yet in its infancy. Speaking of it in its smaller applications, he considered there were many other uses to be made of it. There must be before long a sort of pneumatic telegraph in operation. Tubes must be laid between such points as Westminster and the City, and between Westminster Hall and the New Law Courts, for the transmission of briefs and sealed letters, and this would be a profitable and valuable application of the system. Then, again, in Government offices, a series of tubes, from one set of offices to another, and from room to room, would save the expense of many porters, and enable the officials to place themselves in instantaneous and perfect communication with each other; and, finally, the day must come when the letters of London and other large towns would be collected by the pneumatic system, and distributed by the same means.

Mr. **Latimer Clark** wished it to be understood, that he was the engineer to the Electric Telegraph Company from 1853 to 1860. During the whole of that period Mr. Varley's duties were confined entirely to electrical matters, and he had nothing to do with the pneumatic apparatus until after the year last named.

Mr. R. S. **Culley** observed that he would state exactly what was the performance of the new tube laid by the Messrs. Siemens, and in what it differed from that of the old tubes. As had already been stated, the new tube was of wrought iron with butt joints, secured by double collars caulked with lead. The older tubes were of lead; the joints were plumber's joints made on a heated steel mandril, and in effect the bore was uniform throughout, the joints being as smooth as the rest of the pipe, while in the iron pipe each joint must perforce show a slight unevenness.

He was unable to say exactly what was the difference of friction in the two, but although the iron pipes were carefully cleaned, and those west of the General Post Office were even well scoured with sand, the difference in wear and tear of carriers was considerable, and there was greater difficulty in starting a carrier, which might have stuck fast, in the iron pipe than in the lead pipe.

It had been found necessary to re-cover with felt eighty-two dozen carriers in three months for use in the iron pipe, as compared with thirty-eight dozen for all the lead pipes taken together.

The cost of these repairs for three months was, in labour only,

	£	*s.*	*d.*
For those used in the iron pipes	12	6	0
For those used in the lead pipes	3	8	1

Part of this extra cost of the carriers used in the iron pipe was due to their larger size.

The number of carriers sent and received by the pneumatic tubes on that day (November 21st, 1871), between the hours 11 A.M. and 4 P.M., were as follows:—

IRON TUBES.

Sent to	G. P. O., Charing Cross, Temple Bar. . .	80
Received from	„ „ „ „ . .	55
		135

LEAD TUBES.

Sent	by 2¼-inch tubes	689
Received	„ „ „ „	481
Sent	„ 1½-inch „	187
Received	„ „ „ „	340
	Total sent and received . .	1,697

Many more train miles of carriers were sent in the lead than in the iron pipes. The lead pipes led to eleven stations, beside the house pipes, the total length being 5,974 yards. The iron pipes led to three stations, and their total length was 6,826 yards.

Never since the joints of the lead pipes were soldered had there been trouble from water, while there was apparently constant leakage into the iron ones, in addition to the water deposited by condensation. Although this water generally drained into the dust boxes, and could be pumped out, he feared sufficient might always remain in the spaces between the ends of the pipes to give trouble, by freezing and forming a ring of ice, small, perhaps, in itself, but sufficient to stop a carrier. Besides this, there was great danger that the messages might be damaged by the water, so much so that the carriers for the iron pipes had all closely fitting lids, a precaution wholly unnecessary in the case of the lead pipes. In fact, since the joints had been soldered, there had never been a block in the lead pipes which was not removable with comparatively little trouble, while the iron pipe in Gresham Street had to be opened last winter to take out three carriers which had been frozen together at a joint. Taking all things into account, allowing that the iron would become smoother, month by month, his present opinion was that lead must be used for the large system which was contemplated in connection with the new Post Office in St. Martin's-le-Grand. Many of these pipes must be 3 inches in diameter, and as this was a large size for lead, it would be desirable to use the compound pipe, tin covered with lead, were it not for the difficulty in soldering the joints. An iron pipe, lined with lead, could be used if the lining projected far enough at each end for soldering. The joint could then be protected with a slide.

The Siemens' system was now used as two separate pipes, one for up, and the other for down traffic, the junction piece at Charing Cross having been removed; so that while the continuous current of air was still employed, the circuit had been abandoned.

When the two pipes were connected, and the system worked by pressure at one end and vacuum at the other,

The time occupied in transmission by an up carrier was . .	6·5	min.
And for a down carrier	12·5	„
Together	19·0	„

When the two pipes were separated, but the air still kept constantly in motion, one pipe being worked by vacuum only, the other by pressure only,

The time for an up-carrier was	8·5	min.
And for a down carrier	11·3	„
Together	19·8	„

The sum of the two journeys being practically the same as when the tubes were connected.

It was found that in working the circuit, the forces applied at each end being equal, the neutral point, or the point at which the air was at atmospheric pressure, was not at Charing Cross the centre of the circuit, but considerably nearer the vacuum end, so that the down carriers were retarded by the friction of the air in the portion beyond Charing Cross, while the up carriers leaving that station were affected by the pressure which existed at that point, and in consequence had a higher velocity at starting. Disconnecting the two pipes, there was a gain on the down journey and a loss on the up journey, and it so happened that the traffic could be best conducted in this way, as the down traffic required the greatest despatch.

Fig. 2 (p. 28), showed the velocity at any point of the tube under three conditions: pressure and vacuum, pressure only, and vacuum only. The initial velocity in each case was estimated, and the ordinates at each station were the mean velocities between that station and the one preceding it. They were calculated by dividing the distance between the stations by the time of transit from the one to the other. It should be explained that, as the carriers could not pass the junction curve at Charing Cross, they were taken out from one pipe and replaced in the other by hand, the time occupied being allowed for. This remark applied to all experiments where the speed was given through the entire length of the double pipe.

The times of transit through the looped pipes of 6,826 yards, 3 inches in diameter, were—

	m.	s.
With 20 inches vacuum alone	32	47
With 10 lbs. pressure alone	24	42
With vacuum and pressure combined	16	15

or nearly in the proportion of 4, 3, and 2.

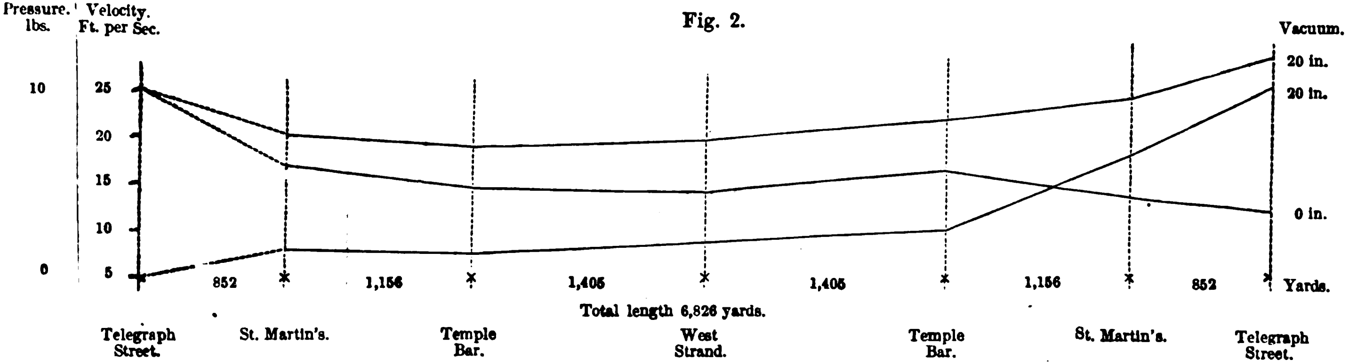
	m.	s.
The time of transit through the looped pipes of 6,826 yards was . . .	32	47
„ „ through one of the pipes, or 3,413 yards	9	48
„ „ and through a portion of the same pipe of 2,008 yds.	4	2

The effect of the weight of the carrier on its speed through 3,413 yards of the same pipe was:

Weight of Carrier.	Time of Transit.			
	With Vacuum.		With Pressure.	
	m.	s.	m.	s.
6 oz.	7	50	6	37
9 oz.	..		7	15
12 oz.	8	20	11	11

It was stated in the Paper that the older system had a very limited power of despatching messages except for short lengths, as it was necessary to wait till a carrier had completed its journey before another could be sent in the opposite direction. This was

Fig. 2.



Upper Line: with P and V total time of transit 16 min. 15 sec.
Middle Line: with P „ „ 24 „ 42 „
Lower Line: with V „ „ 32 „ 47 „

true, but he submitted that it was not from any peculiarity in the old system that a single line of pipe could not do as much work as a double line. A double line would have been laid at any moment, even in the earliest days, had it been needed; but up to the present time, it had not been wanted except at Liverpool, and here two pipes were laid when preparations were made for the transfer of the telegraphs to the Government. Moreover, in this case the traffic was so great that the carriers in the vacuum pipe followed so closely that there was not time to shut off the vacuum; and in consequence, the old system of intermitting currents had developed itself into the new system of a continuous current.

With regard to the relative advantages of the old system of distinct pipes for each station, and that of stations arranged in a circuit, it was a question of traffic and of speed. Where great speed was required the circular system with intermediate stations would not apply, and for that reason it would certainly not apply to the City system. The number of local messages passing between London stations was far less than the number between them and the central station; so that it was of the first importance to provide for the promptest service to the latter. Now to group several stations in a circle the length of the pipe must be more than doubled and the speed would therefore be proportionately lowered. For instance, if a circuit were established from the General Post Office up Fleet Street, across to Holborn by way of Chancery Lane, and thence back by Newgate Street, with stations in each street, and if the course of the carriers were in the same direction, a carrier from Fleet Street for the central station must pass through a considerable length of tube and be subjected to a delay very much greater than if it had been despatched by a separate pipe direct to St. Martin's. It was considered that when the telegraph central office was removed to the new Post Office, it would be necessary to lay separate pipes to all the principal City offices; and, more than this, it was thought many of these lines must be doubled in order to provide for the traffic. And in any case where the time of transit exceeded five minutes the pneumatic system must be superseded by the telegraph.

It had been said that intermediate stations could not be inserted into a pipe worked on the old system; but he did not anticipate much difficulty on that score. It had been proposed some years since, and the trial would have been made by the Electric Telegraph Company had it not been for the expected purchase of the telegraphs.

As to the block system, by which no two carriers were allowed to be in the same section at the same time, he considered that although this precaution limited the traffic it was necessary for a long pipe even where the current was uniform. In practice, no two carriers passed from one station to another in equal times. The speed was influenced by the fit of the carrier, and it so happened that a loosely fitting one would be retarded if it was followed by one which fitted tightly, so that the latter would overtake it. If this happened at a curve or at any place where an obstacle occurred, however slight, the two were liable to stop; and when stopped much extra force was needed to start them again; and the stoppage of a tube was a very serious matter.

The Siemens system of despatching the carriers was simple and excellent; all that was wanted in the way of improvement was that the sliding chamber should be more easily moved, an object of importance where there were many lines of tube.

The blower was a most elegant apparatus. The inventor admitted that, with steam pressure of 40 lbs. to the inch, it was not so efficient as a pump, but in many cases even with this low pressure it would be very useful. If it were possible to fix one at Charing Cross it would be of essential service, but this could not be done; nevertheless he trusted that an opportunity of trying it in practice would soon arise.

Mr. E. A. Cowper remarked, in reference to tubular conveyance in circuits, as now carried out by Mr. Siemens, that he believed the system of circuits, continually going, was preferable, for small and light despatches, to any intermittently worked line, partly because so much more work could be done with a given size of tube and a small engine power, and this was a vital point with all tubular conveyance arrangements. No doubt as long as a tube would conveniently take all that was required of it, even when worked intermittently, there was not the necessity to work it continuously. Mr. Siemens, he knew, had contemplated the use of a signal hammer or bell, or other alarum, on the pipe some 150 or 200 feet away from the station, so that the person in charge should have warning of any despatch coming, and if he knew it was the one intended for him he should have time to take it out, but if it was not for him he should let it go by, simply sounding a bell as it passed. Possibly it might be worth while to have a sort of "cataract alarum" at the receiving station, that should be let go when a despatch was sent off for that particular office, and such alarum might run on measuring the time till the despatch ought just to be about to arrive, when it should give warning of the near approach of the despatch. This measurer of the time of transit would be capable of adjustment by the person in charge of the receiving station, so that if it ran down too quickly he could make it go slower, or vice versâ, thus enabling the despatches to be placed nearer together in the tube. But to reap the full benefit of the circuit system by the sending of despatches quickly one after the other, the vacuum in the reservoir connected to the tube must be kept pretty regular, and the pressure also, if used. This, unfortunately, could not be done at Telegraph Street station, as there were many tubes taking despatches to different parts, which caused irregularities in the vacuum and pressure. It would be advisable to have the pistons or despatch boxes all made exactly alike, and all kept in good order, to maintain uniformity of speed in their transit.

It seemed to be the opinion of Mr. Culley that water got into the pipes at the joints, but this could hardly be the case, unless there were a vacuum in the pipe at those places to draw it in. There was, however, a simple explanation of the cause of water being present in the pressure pipe, and it was this: the air-pump compressing the air was properly placed in a tank of cold water to keep down its temperature, which would otherwise rise considerably from the heat given off by the air during compression; but, besides this, a small injection or jet of cold water was allowed to flow into the pump to further assist in keeping down the temperature; then, unfortunately, the warm compressed air, having a greater capacity for holding vapour in suspension, took up a quantity, and thus it passed with the air into the cold pipes laid in the street, and some of the vapour was condensed there, particularly as the air expanded down towards atmospheric pressure. He did not wish it to be understood that he objected to the compressing air-pumps being placed in cold water; indeed for the last twenty-two years he had thus arranged compressing air-pumps, some of which worked up to 70 lbs. per square inch, and dry air being required, no injection was used and the pumps worked thoroughly well. But in some larger pumps 22½ inches in diameter, of 4 feet 4 inches stroke, compressing to 46 lbs. per square inch, he had not only placed the pumps in cold water, but had put on a ¼-inch injection to each pump. In this case, he knew that the water did not all separate from the compressed air, although it had to pass through two good reservoirs with drains to them before it was used; but it always formed a fog when let down to atmospheric pressure, thus showing how much water it had held in suspension.

At first sight, the fact of using a blower at Charing Cross to exhaust a 3-inch pipe open at Telegraph Street, and another pipe with another blower at Telegraph Street and open at Charing Cross, looked like cutting the circuit; but a single attendant at each end to change or switch the despatches from one pipe to the other, as fast as they arrived, would keep up the circulation and cause no delay; and when working with a regular pressure of air and a regular vacuum, the rates of travelling of the despatches (all the carriers being made alike) would enable one minute or half minute intervals to be kept between them. The blowers were simple and effective. Experiments were made with the three fixed at Telegraph Street, and Mr. Bramwell and himself took notes of their performance.

One blower	gave	a vacuum	equivalent to	8	inches	of mercury	
Two blowers	„	„	„	11	„	„	in 1 minute.
Two blowers	„	„	„	12	„	„	in 2 minutes.
Two blowers	„	„	„	12¼	„	„	in 2¼ minutes.
Three blowers	„	„	„	14	„	„	in half a minute.
Three blowers	„	„	„	14¼	„	„	in 1 minute.

He believed this system was very good for just the work it was used for, or very similar work, say for telegrams or letters on which there was no objection to pay a good freight; but he believed it was altogether unsuited for passengers and goods, or even for heavy mails, on account of the excessive cost of doing either a large or a small business in them. Referring again to Mr. Siemens' arrangement with pipes 3 inches in diameter, and a speed of 14 miles an hour, through 2⅓ miles length, he would wish to direct attention to the great friction that air met with in passing quickly through long pipes; in this case there was a pressure of 7 lbs. per square inch on an area of 7 square inches = 49 lbs. pressure (not on the despatch, for that could not take ¼ lb. in any case), but pressing the air through the pipe, and that only at a moderate velocity, through a moderate length.

He believed many people, from the time of Vallance downwards, had erroneous ideas as to the friction of air through long pipes. He would just refer to the effect of reducing the 3-inch pipe to one-sixth the size, viz., to ½ inch in diameter; then to obtain the same speed it would be necessary first to have a vacuum of 7 lbs. per square inch at one end, and a pressure of 235 lbs. per square inch at the other end, or a total of 242 lbs. pressure per square inch to drive the air through the ½ inch pipe at 14 miles per hour.

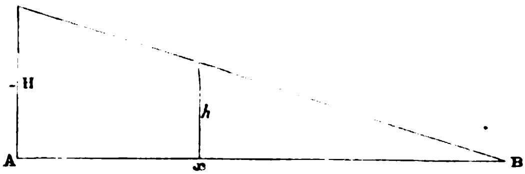
He could not agree with Mr. Varley that the length of tube through which a piston might be driven at a fair speed by compressed air, or by atmospheric air passing into an empty space, depended upon the tightness of the piston in the tube, for if it was tight enough to be driven at a certain speed through a short tube, it would be tight enough to be driven at the same speed through a long tube; the only difficulty that arose in driving a piston through a long tube arose from the great friction of the air in the tube.

Then, again, if it were attempted to carry heavy mails at high speed through tubes, first, in order to get the speed the friction must be reduced by increasing the size of the tube, and then, with the high pressure and vacuum still required, the large quantity of air to be pumped, and the high velocity, the power necessary would be enormous. Thus a pipe 24 inches in diameter, 4 miles long, with a vacuum of 11 lbs. per square inch, would only give a speed of 47 miles per hour, though with proper arrangements for letting in the air, at ½ mile distances, and arrangements for maintaining the vacuum whilst the despatch was running, a speed of about 131 miles an hour might be maintained, if the despatch or piston would stand the wear and tear. The power required, however, would be very great, viz., about 390 H.P. every 4 miles, which in first cost, and in working, would be exceedingly expensive on a long line, on which alone it would be valuable for saving time. He might mention that, having been called in with Mr. Gregory in 1855, by the Post Office authorities, to advise on these matters, they examined thoroughly the whole system, both for the London centres and branches, as well as for expediting the Irish mail to Crewe or Holyhead; and they found the expense very much against the system for high speeds and heavy weights. The plan proposed for London consisted of two pipes 13 inches in diameter to exchange despatches between the eastern central and the western central offices, with engine power at each, to work together or separately, and then, for economical reasons, only single pipes 9 inches in diameter from the centres to the eight branch offices, and these latter were to be worked by pressure and by vacuum alternately, to send or draw despatches from or to the centres. To Sir Rowland Hill was due the merit of having had this means for the conveyance of letters thoroughly investigated as far back as 1855, and no doubt some time might be saved in the conveyance of ordinary letters in London, but inasmuch as a letter was more generally two and a half to three hours in the hands of the Post Office authorities on an average in London, the actual saving of a few minutes in the transit of the letter from office to office amounted to no more than the difference in speed of a mail cart and the despatch in the tube, for the short distance traversed, so that the heavy outlay would be made for only a small gain of time, say about twelve minutes. It need hardly be noticed that the sorting and the delivery of letters took up by far the larger part of the time, particularly as letters had to be accumulated before being dealt with.

Mr. W. H. Preece observed that, however desirable it was to establish a pneumatic system in large towns, there was a limit to the length to which it should be extended. The Postal Telegraph Department could not afford to allow messages to be delayed beneath the streets of London for a longer time than would be occupied in their transmission from London to Liverpool; and he thought that five minutes was the utmost delay that could be admitted. Hence it was not advisable to employ the pneumatic system when a greater delay than this limit was introduced.

With reference to the laws of pneumatic transmission through pipes, in the case of two stations, A and B, connected together by a straight level pipe open at each end, but perfectly air-tight along its whole length, and of uniform diameter, let it be assumed that it was required to transfer a small well-fitting piston or carrier from the one place to the other by pneumatic power. What was the law which regulated the rate of motion of the carrier through the pipe, and what, therefore, would be the time occupied by the carrier in its transference from A to B? The motion of air from one point of space to another was simply due to a difference of pressure at those points, the direction of this motion being always from the higher to the lower pressure. The same condition precisely obtained in a pipe; and, taking an extreme case, if there were a perfect vacuum at B, and A were open to the atmosphere, the pressure at A might be called H, and that at B might be called *o*.

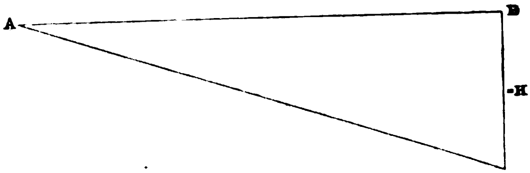
Fig. 3.



If the pressure at A, equal to the weight of a column of the atmosphere, whose base was unit area, were indicated by a vertical ordinate H, that of B being nothing, the hypothenuse of the triangle would, after a very short interval, represent the variation of pressure throughout its whole length, a current of air would be established, and the pressure at any point x would be to that at A as $h : H$.[1]

Similarly, if the mean ordinary pressure of the atmosphere were made the zero line, the distribution of pressure could be represented as in

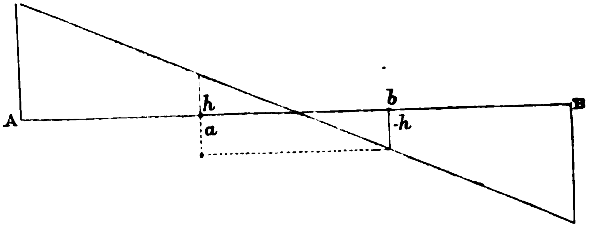
Fig. 4.



giving the vacuum the minus sign. Now if it were assumed that the end B was open to the atmosphere, and that a plenum was applied at A, whose pressure = H, then after a short interval a current of air would be established as before, and the distribution of pressure would be as in Fig. 3.

The same distribution precisely occurred under the same conditions when there was a vacuum at B and a plenum at A, and it was represented in Fig. 5.

Fig. 5.



Under these conditions, therefore, there would be between any two points a and b a uniform and constant current of air, due simply to the difference of pressure between those two points. Thus if h were the pressure at a, and $-h$ that at b, $h-(-h)$ or $2h$ would be the pressure determining this motion from a to b. The same quantity of air that entered at A must pass out at B in the same interval of time, otherwise there would be an accumulation of air at some point which was inadmissible.

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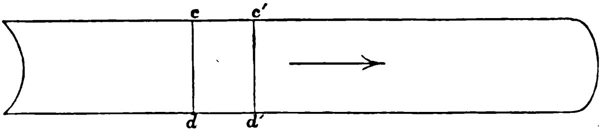
[1] This uniform distribution of pressure along a straight level pipe is objected to, because the density of the air must vary as the open end is approached; but it must be remembered that the density varies with the pressure, and not the pressure with the density. Pressure is the independent, density the dependent variable.—W. H. P.

Let it now be assumed that a light carrier had been inserted in the pipe, and that it was required to move it from *c d* to *c′ d′* Fig. 6:

Fig. 6.



The carrier possessing weight, and having tight-fitting collars which exerted considerable friction, it was evident that to produce motion along a level pipe force must be exerted upon it in the direction of its length. This force might be either due to the projection of the particles of air against it, or to a difference of pressure on either side. Let *c d* and *c′ d′* be two consecutive positions of the moveable piston very close to each other, and let h be the pressure at *c d* and $h + d\,h$ at *c′ d′*, then $d\,h$ would be the force producing motion through the very small space *d d′*; but since it had been shown that the distribution of pressure was uniform, the pressure at any point x might be called h, and at any other point x' might be called h'; and it might be said that the motion of the carrier between those two points was due to a force $h - h'$. Hence the only condition that determined the motion of air or of a carrier from one point of a straight uniform level pipe to another was that there should be a difference of pressure at those two points. But the rate of this motion depended upon the rate of variation of pressure per unit length; or, calling v the rate of motion attained by the carrier, assumed of unit mass, in its passage from one point to another, and l the distance between those points, it would be found that v varied directly as the difference of pressure at those two points, and inversely as the distance separating them, or

$$v \propto \frac{h - h'}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1).$$

The rate of motion therefore being directly proportional to difference of pressure, and inversely proportional to length, the resistance opposed to this motion remained for consideration: calling this resistance (R), it might be stated generally that, all other things remaining equal, the rate of motion varied inversely as the resistance, or

$$v \propto \frac{1}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

This resistance depended, firstly, on the dimensions of the pipe; secondly, on the friction exerted between both the air and the piston and the sides of the pipe. Now, whatever resistance a given length of pipe opposed to the transference of air through it, a similar length of pipe under similar conditions must oppose precisely the same resistance. Hence between two given points the resistance opposed per unit length of pipe might be considered as constant. Again, if a pipe of a given area allowed a certain quantity of air to pass through in a given time, twice that area would allow twice as much air to pass through, and *n* times that area *n* times as much air; hence

$$R \propto \frac{1}{A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

But resistance also increased directly with the friction exerted by the air and the carrier; so that, calling friction F, it might be stated generally that

$$R \propto \frac{F}{A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4).$$

The friction depended upon the surfaces in contact, the velocity of the current, and on the density of the air. The laws of friction had been thoroughly investigated, and it was well known that friction varied directly with the surfaces in contact (s); the density of the air (ρ), and a certain coefficient (μ), dependent upon the surfaces in contact, and varying in some way not clearly ascertained with the square of the velocity of the air, in the case of the air alone, and independent of the velocity of the carrier in the case of the carrier alone, but which, since the velocity of the carrier was less than that of air, might be assumed within the limits under consideration as constant; therefore

$$F \propto s\rho;$$

and substituting this value of F in (4),

$$R \propto \frac{s\rho}{A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5).$$

The only conditions that the carrier introduced to retard motion were its mass w, and the coefficient of friction μ', which was constant between its collar and the pipe. Hence also

$$R \propto w.$$

Now, combining all these variations,

$$R \propto \frac{w\,s\,\rho}{A} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6).$$

or converting that variation into an equation,

$$R = m\,\frac{w\,s\,\rho}{A} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7).$$

This factor m was simply a constant due to the units of measurement adopted, and to the coefficients of friction of the air μ and the collars of the carriers μ'; s, the internal circumference of the pipe, $= \pi\,d$, and A, the area of the circular section, $= \frac{\pi}{4}\,d^2$, calling d the diameter of the pipe. Hence, substituting these values for s and A in (7),

$$R = 4\,m \cdot \frac{w\,\rho}{d} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7').$$

Now, calling L the whole length of the pipe, since $v \propto \left(\frac{h - h'}{L}\right)$ and $\propto \frac{1}{R}$, these could be put in the form of an equation, so that

$$v = m'\,\frac{h - h'}{L\,R}$$

$$= \frac{m'(h - h')}{4\,m\,\rho \times \frac{w}{d} \times L}$$

or putting $\frac{m'}{4m} = K$

$$v = K\,\frac{(h - h')\,d}{L\,\rho\,w} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8).$$

Now ρ, the density of the air, varied at any point with the pressure at that point, and was therefore a variable quantity; but by calling ρ the mean density of the air between A and B, its invariable character was retained.

This being the rate of motion of the carrier, and the motion being uniform, it was simply required to substitute for v its value $\frac{L}{t}$, or length divided by time, and the result was

$$t = \frac{L^2\,\rho\,w}{K(h - h')\,d} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9).$$

The pipe was assumed to be straight, uniform, and level; and the pressures uniformly distributed. But it was neither straight, nor level. Bends and curves, horizontal and vertical, occurred in its path in practice, and thus corrections due to centrifugal force had to be made.

The pressures had also been assumed to be uniformly distributed; but this was only approximately correct in practice. The distribution of pressure was disturbed by difference of temperature, by the changes in the condition of the atmosphere, by leakages into the pipe, by irregular velocities due to curves and obstructions, and by variations in the resistance opposed by different carriers.[1]

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[1] Experimental verification of the formula

$$t = \frac{L^2 \rho w}{K(h - h')d}.$$

1. The distribution of pressure was uniform.

In the case of two series of observations taken in August and on November 20th 1871, the first observation was made when the whole pipe, 6,826 yards in length, was joined up in one length, and a plenum applied at one end and a vacuum at the other. The second observation was made upon each half when the ends were open to the atmosphere at Charing Cross. Observations taken at the intermediate stations upon gauges confirmed very strikingly the fact that pressure was uniformly distributed.

2. The speed of transmission varied inversely as the difference of pressure $(h - h')$.

Length, 852 yards.

$h - h'$	t
V 3	1·38
P 1·5	2·32

Length, 1,156 yards.

$h - h'$	t
V 4	2·30
P 1·5	4·55

Length, 1,405 yards.

$h - h'$	t
P 3·5	3·4 3 6
V 3·5	3·8 3·11

Length, 3,413 yards.

$h - h'$	t m.	t s.	
9	7	2	average of 21 trials.
3·6	17	1	

Length, 6,826 yards.

$h - h'$	t
20	16·15
10	32·47

3. The speed of transmission varied with the weight of the carrier.

Weight in oz.	Time ($h - h'$ constant).		Ratio.	
	m.	s.	Mass.	Speed.
6	6	40	100	100
9	7	15	149	109
12	11	10	200	168

It would be seen in all these instances that there was a close approach to

Mr. **Bramwell** said he believed Mr. Preece's formulæ were incorrect, because the diagram showed as the result of them that, in any given length of pipe through which air was being either propelled or drawn, the pressure varied directly as the length of the pipe. Taking the length of the pipe as the base line of his figure, he erected a vertical line at the end at which the air was entering, representing the total difference in pressure between the air as it entered at that end and the air as it left at the opposite end, and representing this total difference, whether it was due to a forcing of air in at the entrance end by some apparatus which produced the amount of pressure above atmosphere indicated by the vertical line, or whether it was due to the difference between atmospheric pressure at the entering end and the reduction of that pressure at the outgoing end, caused by some species of exhausting machinery. From the top of this vertical line, placed at the entering end of the pipe, Mr. Preece drew a sloping straight line to the outgoing end of the pipe, and said that, to find the pressure at any intermediate point, nothing more was necessary than to take the height between the base line and this sloping line, and that the height so ascertained would represent the pressure.

Now Mr. Bramwell had endeavoured, in vain, to find out what was the true law of variation of pressure in the movement of air through pipes under the conditions specified, and how to express that law by a diagram; but although he had not suc-

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accuracy; and if the effect of centrifugal force were taken into consideration, there would be a still more accurate analogy between the law and the observations.

4. The speed varied directly with the square of the length $(h - h')$ constant.

Length.	Time.	Ratio of Squares.	Ratio of Time.
Yards.	m. s.		
6,826	32·47	11·56	8·13
3,413	9·48	2·89	2·43
2,008	4·2	1	1

5. The speed varied inversely as the diameter of the pipe.

Length	Diameter.	Time.		Ratio of Diameter.
		Pressure.	Vacuum.	
Yards.		s.	s.	
590	2¼	35	38	35
588	1½	40	51	52

	Diameter.		Feet.		Ratio of Diameter.
Leadenhall Street tube .	2¼	velocity	52·8	per second	52
Gresham House „ .	1½	„	34·5	„	35

ceeded in discovering what was the true law, he felt sure he had succeeded in ascertaining that the law put forward by Mr. Preece could not be true.

Mr. Preece's law would be true for water or other practically non-elastic fluid, for there it was well known and confirmed, both by theory and experience, that the friction, or skin-resistance, increased exactly with the increase in the length of the pipe; and it was also true that in the passage of gas through gas-mains such a law was practically true, although gas was as elastic a fluid as air; but the reason why the rule that related to water or other non-elastic fluids could in practice be safely applied to the transmission of a highly elastic fluid like gas was this, that in order to get rid of any inconvenient pressure in the gas pipes the pipes were made of such size that the mere difference, equal to a head of 5 inches or 6 inches of water, was all that was used to propel the gas through the pipes, or even less than this; the fact being that the extreme pressure at the gas-holders was not above 6 inches, and the terminal pressure at the end of the main was probably 2 inches or 3 inches, leaving only 3 inches of differential pressure to do the work. This was true even of the 10-mile main from Beckton to London.

Now under these circumstances the gas, although highly elastic, might be treated for all practical purposes as of uniform density throughout. Even assuming an actual difference in pressure between the two ends of the main of 6 inches of water, it would only represent about $\frac{1}{64}$th of variation in the bulk, and in actual practice, the pressure being less than 6 inches, it was not much more than $\frac{1}{100}$th; and thus it was that in the instance of gas-works, although dealing with a fluid as elastic as air, yet as the mains were made so large as to work with extremely low pressures, these pressures were not sufficient to bring into play appreciably the expansibility of the gas. But, in the case of the pneumatic tubes under consideration, it had been stated that there were pressures used equal to $\frac{1}{2}$ an atmosphere; in such cases, therefore, it was manifest if it were done by exhaustion that the air at the outlet end of the pipe would be doubled in bulk compared with the space it occupied at the inlet end. Now, if doubled in bulk, it must travel through the pipe at double the pace to withdraw from the outlet end of the pipe the same weight of air, in a given time, that was coming in at the inlet end in the same time.

But it was well known that skin-resistance increased as the square of the velocity; it was also known that it varied directly with the density. Now, as in the case under consideration the velocity increased directly as the density diminished, it followed that the extra friction put on would be directly as the increase in bulk, or the increase in velocity; because, although it would increase as the square of the velocity, it would diminish directly with the density, leaving, therefore, the increase simply in the ratio of the velocity.

It was manifest that in the case of a water main, or in that of a gas main working under a few inches only of pressure, the velocity was uniform from end to end; and it was known that such a diagram as Mr. Preece had put forward would be true for the motion of water or of gas; it was clear, therefore, it could not be true for the motion of air when subjected to a difference in pressure such that the velocity, instead of being uniform, was doubled in the course of the length of the pipe. It was clear, too, that the line from the point of highest pressure to the end of the pipe, instead of being a straight sloping line should be a curved one.

Nothing apparently could be more successful than the arrangement for receiving and transmitting the messages in Telegraph Street. He had inspected the machinery for the purpose of forcing and exhausting the air, including the steam jet exhausters of Mr. Siemens, and had hoped to be able to make some test as to the consumption of power by the different machines, but he found it impossible to do so, because some of the systems were being worked on the continuous plan, and some by the plan of alternate pressure and exhaustion; and these different systems were being driven off air vessels into which two or three engines were pumping air, and exhausted vessels from which engines were drawing. The boilers also that supplied the exhausters supplied the engines. The utmost that could be done in the way of an experiment was to shut off from one of the exhausted vessels the suction pipe of the exhaust pump, and to keep up the exhaust by means of the steam exhausters. This was done, with results as stated by Mr. Cowper. On calculating these, and taking the amount of air drawn in to the exhausted vessel, coupled with the minus pressure at which it was drawn in as representing useful work done, he found that if the work done by one exhauster was assumed as equal to 100, the work done by two was equal to 184, and the work done by three was equal to 235.

The question of making use of induced currents was a most interesting one. Its application was well known in Gurney's jet for ventilating mines, in the ordinary blast pipe of a locomotive, in Giffard's injector, and in Morton's ejector-condenser. He believed that Mr. Siemens had devised a good and economic form of jet, but he much doubted whether, upon careful trial, it would be found to give results equal to those which could be obtained by working steam through a steam engine; nor did he think, indeed, it was possible to obtain such results by any contrivance of steam jet that could be made. He thought, however, there might be a near approximation to the best result, and if there were, then, looking at the fact that three or four simple implements replaced the whole elaborate machinery of steam engines and pumps, and that their original cost, cost of working—other than fuel, and cost of repair,—were but a small fraction of the original cost of construction and maintaining a steam engine and pumps, he thought it might well be that, commercially considered, especially where coals were not very dear, the steam exhauster would be the most efficient implement. He also thought that the exhausters at Telegraph Street were not under favourable conditions, because they were working with comparatively low steam pressure, that was, steam of only about 60 lbs. per square inch, which he called low for such a purpose.

He doubted whether increasing the diameter of the pipe for an increase of length was an economic way of getting over the difficulty attendant upon the use of greater lengths of pipe, because although the amount of "exhaust" remained the same, the quantity of air that had to be drawn out in a given time would, if the diameter of the pipe were doubled, be four times as great. He believed it would be found more economical not only in first cost, but also in the working, to retain the same diameter of pipe and to overcome the increased length, not by increased exhaustion but by increased pressure. It seemed to him, however, that the right way of dealing with long lengths was, as suggested by Mr. Cowper, to have exhausting or pumping stations at frequent intervals. He thought there would be no difficulty in making the end of the tube at such a station with a valve, so that the carrier should by its momentum be able to open that valve, come out, and enter the next section of the tube.

He would just venture one other idea, and that was as to the feasibility of working a continuous circuit by means of hydrogen gas. If this could be done, then, as the skin resistance decreased directly with the decrease in density, it followed that by the use of pure hydrogen the skin resistance might be reduced to $\frac{1}{16}$th of that which it would be if air were used. But without going to the extent of supposing that pure hydrogen would be obtained, there were very cheap and simple means by which a moderately pure gas, one certainly of only $\frac{1}{10}$th of the density of atmospheric air, might be manufactured, and the use of such a gas would clearly most materially reduce the skin resistance.

Mr. W. Pole said that shortly before the application referred to by Mr. Siemens, was introduced, the Post Office authorities, being probably attracted by the working of the pneumatic apparatus at Euston Square, had thought that the power for these tubes might be more advantageously obtained by increasing the size of the tubes, and working them with a lower pressure of air produced by a fan. They commissioned Mr. Gregory and himself to make experiments; and for that purpose a pipe 6 inches in diameter, and of some considerable length, was laid in Battersea Park, and worked by a good fan driven by a small engine. The conclusion arrived at was that the fan power would not give sufficient pressure, unless the pipe were made so large as to be cumbrous, and larger than was actually necessary for the purpose; for a small pipe high pressure was indispensable. If the pipe was increased in size the fan would do; but even then it took a large power, for though the pressure was small the quantity of air required was large. The real datum was what was required to be done in the tube. If a small carrier was sufficient it was useless to put it in a large tube; it was best to use the pressure necessary for the small diameter. In considering, however, the application of the pneumatic system to carrying a bulk of letters, a diameter of tube might be arrived at in which the small pressure of a fan would be better than the larger pressure induced by a pump. At Euston Square the pressure was sufficient, and it would only be a waste of power to give a larger pressure. Mr. Gregory and Mr. Pole, therefore, advised the Post Office, that if the purpose was to convey small messages it would be better to adhere to tubes of small diameter and high pressure; but when larger objects had to be dealt with, then would be the time to consider whether the fan might not be the best means of producing the power.

With regard to the calculation of Mr. Preece, he was inclined to think, with Mr. Bramwell, that the question was not to be solved so easily as Mr. Preece supposed. When velocities and masses in motion were to be calculated, certain dynamic considerations came in which, he thought, had not been taken into account; this, however, was a matter that would hardly admit of verbal discussion; when the calculations were printed they would speak for themselves, and be open to the test of examination at leisure.

Mr. F. H. Ricketts remarked that the carriers used by the Post

Office were covered with felt, which appeared to have acted well through leaden pipes, but they wore very rapidly when used through iron pipes. He had received from Berlin, and he exhibited, a carrier covered with leather, which appeared more suitable for iron pipes. It had run 10,000,000 feet, while the usual life of such a carrier was 11,000,000 English feet. As to the joints in the pipes, it might be inferred from what Mr. Culley had said that water was allowed to get in, but he thought the fact that water was found only in the pressure pipe, and not in the vacuum pipe, proved that it must be forced in at the end of the pipe by the engine; for, if the water came in through the joints, it would be found in the vacuum rather than in the pressure pipe.

Mr. W. C. **Unwin** wished to make some remarks on the principles involved in the action of tubes on Mr. Siemens' system. Mr. Siemens had exhibited some formulæ about which Mr. Culley had observed, that they, like all the ordinary formulæ for the motion of air and gas in pipes, were completely erroneous when applied to calculate the motion of the carriers in the pneumatic tubes. Mr. Preece, also, had proposed some formulæ for the motion of air, with regard to which he might venture to say, that Mr. Preece had not given an intelligible reason for the law of motion which he had assumed. No doubt Mr. Preece had experimental or other reasons for the formulæ he had proposed; but he had not shown that those formulæ were based on principles which were generally acknowledged as applicable to the case. He had not examined Mr. Siemens' formulæ with any care, but from their form they appeared to be based on the assumption that the air flowed under such small differences of pressure, that its variation of volume might be neglected. Now, in the pneumatic tube, described in the Paper, the absolute pressure at one end was 22 lbs. per square inch, and at the other only about 5¼ lbs., so that the air expanded in passing through the tube to four times its original volume. Each cubic foot of air entering the tube at one end would be expanded to about 4 cubic feet before reaching the other. In such circumstances it was clear that to treat the air as having constant volume was to introduce a very great error. Now the principles on which the flow of air or gas under great differences of pressure could be computed were understood, and were not very difficult to apply to the case of Mr. Siemens' tubes, in which a constant or steady current passed through the tube. Without using symbols, it was possible to indicate two principles on which the formulæ for the velocity of the carriers in those tubes must be based. He assumed that the resistance of the carriers was very small compared with the frictional resistance of the tubes, so that, for practical purposes, the velocity of the carrier might be considered to be identical with that of the steady current of air flowing through the tube. The resistance of the carrier could be taken into account if necessary, but it would complicate the question, and, for the present, the motion of a steady current of air only would be discussed. The first principle to be attended to was this: the flow of weight was constant. With an inelastic current, such as water, the flow of volume was constant; but with an elastic medium, such as air, the flow of volume varied and the flow of weight was constant. That was, if 100 lbs. of air entered one end of the tube per second, then 100 lbs. left the other end per second, and 100 lbs. passed every point of the tube per second. That principle, together with the known laws of gases, furnished the relative velocity in terms of the pressure at every point of the tube. The second principle was this: that the work done by the pressure and expansion of the air on the one side, and expended in overcoming the resistances of the tube, and in generating velocity in the air on the other, must be equal. Or, to put it in the form of an equation, the work done by the pressure in the reservoir, in forcing air into the tube, + the work due to expansion of the air in the tube, must be equal to the work expended in forcing the air out at the other end of the tube, + the work expended in overcoming frictional resistances in the tube + the energy in the air leaving the tube.[1]

With these two principles the theoretical difficulties of the problem were completely overcome; but there remained certain practical difficulties in expressing these laws in a formula which could only be overcome by experiment. The first of these difficulties was in settling a form and constant for the expression for the frictional resistances. The second was to determine what law should be assumed for the relation of the pressure and volume of

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[1] The fundamental formula is,

$$p_1 Q_1 + \int_{Q_1}^{Q_2} p\,dQ = p_2 Q_2 + W\frac{v_2^2}{2g} + W\Sigma\zeta\frac{v^2}{2g}\frac{\Delta L}{D},$$

where p_1 p_2 are the initial and final pressures, and Q_1 and Q_2 the initial and final volumes of the air supplied per second, and the last term is used to express the sum of the frictional resistances of the tube. W is the weight of air used per second, l the coefficient of friction, v the velocity corresponding to any element $\Delta\,l$ of the tube, D the internal diameter, and L the total length of the tube. This equation, with the exception of the last term, would be found in Rankine's "Applied Mechanics," and in "Notes on the Steam Engine," by J. H. Cotterill.

the air, or, in other words, to determine under what law the air expanded.

Now, in calculating the flow from orifices, it had been assumed by Rankine and others that the air expanded without loss or gain of heat; then the expansion curve was what was known as an adiabatic curve. In so expanding the air cooled very greatly, and a reason could be assigned why, in the present case, the cooling could not be so great as the adiabatic law of expansion would require.

In this case nearly all the work done was expended in overcoming frictional resistances; and those frictional losses of work resulted in the production of heat. The greater part of the heat so produced would be given back to the air, and would tend to maintain its temperature constant. In this case, as the velocity increased from one end of the tube to the other, he did not believe the temperature would be quite constant. He believed that the air would cool during the expansion, but not very greatly. That was a point easily determined by experiment. Still, in the absence of experiment, he believed it would be sufficiently accurate for practical purposes to assume Marriotte's law.[1] If that were done the expression of the work developed and expended would be simplified. The work done by the pressure in the reservoir, forcing air in at one end, would be equal to the work expended in forcing it out at the other end;[2] and, neglecting for the moment the *vis viva* of the air leaving the tube, which, in the case of the tube described in the Paper, appeared to be comparatively small, there should be this law: the work developed by the expansion of the air in the tube was equal to the work expended in overcoming frictional resistances,[3] at least, very approximately. He had formed a formula for the velocity of the air on this principle, and the results appeared to agree with those previously stated. At the same time, further experiments were required before any satisfactory formula could be deduced. Such experiments should aim, first, at the determination of the variation of the temperature and pressure in the tube, and next, at the determination of the amount of frictional resistance. Such experiments would be easily made;

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[1] $p\,Q = \text{constant}.$

[2] $p_1\,Q_1 = p_2\,Q_2.$

[3] $p_1\,Q_1 \text{ Hyp. log.} \frac{p^1}{p_2} = W\,\Sigma\,\zeta\,\frac{v^2}{2\,g}\,\frac{\Delta\,L}{D}.$

or, putting δ for the weight of a cubic foot of air at the initial pressure and volume,

$$p_1 \text{ Hyp. log} \frac{p_1}{p_2} = \delta\,\Sigma\,\lambda\,\frac{v^2}{2g}\,\frac{\Delta\,L}{D}$$

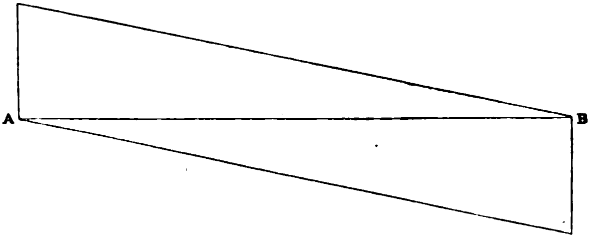
but they should be directed by a clear knowledge of the principles involved. The law just assigned explained why the vacuum part of the tube was so much more effective in giving velocity to the carrier than the pressure part; for the work due to expansion was much greater in the former than in the latter. It might be pointed out, also, that the power required to work the vacuum part of the tube was less than that required to work the pressure part, at a given velocity, on account of the reduced density of the air.

Mr. T. Webster, Q.C., observed that the first phase of this question was when the proposal was made to propel railway carriages by means of compressed air; the next phase was when it was proposed to propel them by vacuum only, which was carried out to a certain extent on the Croydon and South Devon atmospheric railways. The system described in the Paper appeared to be an intermediate one, the combination of vacuum and pressure; and, judging from the results given of one of the instances mentioned, of the employment of both pressure and vacuum, and of vacuum only at the same stations, he thought the comparison extremely valuable. The results given in the Paper afforded a nearer approach to the solution of the question of the constants than had been hitherto attained. He thought the Paper was one of the first that contained a record of successful experiments, giving with great precision the results of diaphragms being passed through tubes under the particular circumstances recorded; and he trusted the subject would not be lost sight of, affording as it did the opportunity of comparing these results with those obtained from experiments with larger tubes and heavier objects transmitted through them, as was done at the Crystal Palace—in some instances by pressure only, in others by the combination of pressure and vacuum. He considered the experiments both with large tubes and small ones showed that it was by the combination of the pressure and vacuum systems that the best results were obtained with the smallest expenditure of power. What led to the failure of the atmospheric system on the railways was that they were worked by vacuum only, and the extreme difficulty of maintaining it: but he thought the Paper gave fair grounds for presuming that the combination of pressure and vacuum would afford a solution of the problem in the most economical manner.

Mr. W. H. Cutler pointed out what he considered to be errors in the formulæ given by Mr. Preece. He considered it clear that if Mr. Preece's two first diagrams were even theoretically correct, it was impossible for the third diagram to be so, but that it should be drawn thus (Fig. 7):

then, ordinates crossing A B at right angles would more correctly illustrate the values supposed to be illustrated by ordinates as

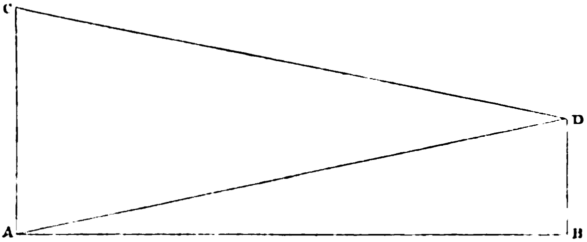
Fig. 7.



taken by Mr. Preece. According to Mr. Preece's diagram there would be neither air, vacuum, nor anything else mid-length in A B.

It was evident that by using a vacuum a better result was obtained than when an equal amount of atmospheric pressure was used without a vacuum; for, the smaller the volume of air that was passed through a tube of given diameter in a given time the less force it took to pass it through. Taking the atmospheric pressure at 15 lbs. on the square inch, then in the one case the volume of air in the tube would be represented by 15 lbs. at one end, tapering off to nothing at the other, and in the other case by 30 lbs. at one end, tapering off to 15 lbs. at the other.

Fig. 8.



In Fig. 8. A B represented the length of the tube;
A C = 30 lbs. pressure on the square inch;
B D = 15 lbs. do. do.
A B D = volume of air when a vacuum was made use of;
and A C D B = volume of air in the other case;

or, in other words, by making use of a vacuum at one end of the tube and the atmospheric pressure at the other, the tube was worked with air of only one-third the density of what it would be in the case of a pressure of two atmospheres at one end of the tube and the atmospheric pressure at the other; and as the friction of forcing air through a tube was found to be directly as its density, then the friction in the one case would be only one-third of what it would be in the other.

Mr. L. THOMAS observed that the exhauster appeared to be an almost identical application of steam with that of water, as applied in the water-jet for the purpose of mine ventilation. The application of a jet of steam to the exhausting of air from shafts, levels, or confined passages, was not, in itself, a novel application of steam. Steam jets had been so used in various ways as an auxiliary to mine ventilation. They were used in this country as early as the year 1811, and later in America; they had not, however, come into general use. On the Continent they were tried with a similar result; and M. Glépin, who experimented on various forms of steam jet, endorsed in his Memoir, "Sur l'aérage des mines," the opinion of its being an uneconomical application of steam. The exhauster described in the Paper was, it was evident from the results already obtained with it, a more perfect appliance; and he believed that there were special circumstances in which it would, from the facility and small cost with which it could be put up, be valuable as a mine ventilator.

It had occurred to him that the pneumatic tube system of transmitting messages was not inapplicable as a means of communication between the surface and underground in deep mines; the cost attending the constant employment of skilled operators militating against the use of the electric telegraph for mine purposes. If the pneumatic system were introduced, steam to work the exhauster might be taken from the boilers of the pumping or drawing engine.

Mr. J. W. BARRY said there was one point which had not been remarked upon in the discussion, viz., What was the good of sending telegrams at this pace through London? It appeared that the most that could be got out of the tube was a speed of 30 miles an hour for telegraph messages; and at this day he thought such a speed of transmission was insufficient. It seemed to him that the expense of sending messages by these means must be large, compared with the result. Taking the expenditure upon the engines, wear and tear, and other expenses of working the tube, and applying them to telegraph clerks, he believed messages could be sent through London more quickly and more economically. It struck him as rather retrograding in these days to send telegrams through London in pneumatic pipes. Moreover, it had been found that a further reduction in the speed of transmission was necessary, as the pneumatic system required working on the telegraphic block system: for the continuous current of air which seemed to be the principle of Mr. Siemens' invention could not be, at present, safely applied, unless the telegraph was used in connection with it, in order to prevent collision of the carriers. Thus, only three or four carriers could be travelling in the tube at one time; and if the tube was occupied at one district at the time when a carrier was to be sent, the carrier had to wait till that division of the tube was free again before it could pass. It seemed a cumbrous machinery to be employed to send the number of messages which he gathered from Mr. Culley's statement could be got through in five hours.

Mr. R. S. CULLEY explained that one carrier, containing twenty-seven messages, could be despatched by Mr. Siemens' tube every eight minutes; and he thought that was cheaper than providing wires and clerks to send the same number of messages in the same time by telegraph. At the greatest rapidity, not more than one message per wire per minute could be sent by telegraph; and working throughout a whole day, perhaps one message might be sent in two minutes; so that with one wire only four messages could be sent in the time occupied by the passage of a carrier. It would then require about seven wires and fourteen clerks to do the work of the 3-inch pipe.

Mr. J. W. BARRY said he understood Mr. Culley also gave the number of messages in the carriers that passed through the tube in five hours. Be that how it might, he would remark that, when he saw the apparatus at work, many carriers arrived with only one message in them; so that it would not be fair, in making a comparison, to assume so large a number of messages in each carrier, unless carriers were detained in order that they might start full.

Mr. R. S. CULLEY observed that he did not know the number of messages which the carriers contained; he gave the number of carriers sent, in order to show the relative wear and tear in iron and leaden pipes.

Mr. C. F. VARLEY remarked that when he was engineer-in-chief of the Electric Telegraph Company, statistics were kept by him of the working between Mincing Lane and Telegraph Street, Cornhill and Telegraph Street, the Royal Exchange and Telegraph Street, Founders Court and Telegraph Street, as well as in Liverpool and Manchester. It was found that the saving in expense, by the number of clerks' salaries dispensed with, was considerably more than the total expenditure of working the engine and the interest upon the capital expended in putting down the pipes. The pipes in question were only laid between busy branch stations and the chief office. The shortest distance was 220 yards, and the longest 1,340 yards. In addition to greater economy in working, it was found to save errors. It cost as much for clerks' salaries, and occupied as much time, to telegraph a message 6 yards as it did 400 miles; and a message from Mincing Lane to Liverpool had first to be telegraphed to Telegraph Street, and then to be re-telegraphed to Liverpool.

A telegraph could only carry one message at a time, while the Mincing Lane pipe would carry fifteen in one carrier. Again, this pipe of 1,340 yards was quicker for a message of thirty words than the wire, and it was therefore more than equal to fifteen wires, each wire requiring one sending clerk and one or two receiving clerks, according to the pressure upon it. The numerous short bends in the tubes prevented any accurate determination of the laws governing the flow of air; and the leakage past the carrier was so great that the carrier's speed was a variable quantity different from the air, and depending more upon the fitting of the carrier than upon the amount of vacuum. All conclusions as to the speed of the air in the tubes, which were based upon experiments with carriers, which were always leaky, were fallacious.

Mr. **Bramwell** asked permission to state the results Mr. Ernest Carpmael had arrived at, in his investigation of the law that regulated the pressure at different portions of a pipe along which air was being driven. They were these: That the pressure increased in such a manner that a figure might be made up of a triangle plus a logarithmic curve, so that the ordinate representing the pressure at any length of the pipe would be compounded of the depth of the triangle at the particular part where the ordinate was taken, and of the depth of the logarithmic curve on the top of the triangle at that part. The triangle would represent the variation in pressure due to the uniform speed of an inelastic fluid, such as water; and the logarithmic curve would allow for the increase of pressure rendered necessary by the acceleration in the flow of an elastic fluid like air caused by its increase in bulk under the diminished pressure.

Mr. **Bazalgette** said he hoped some further information would be given to show under what circumstances the electric wire had the advantage over the tube, and the conditions under which the tube became the best and most economical means of conveying messages. It was evident, as Mr. Barry had stated, that with a smaller number of messages going from place to place, the electric wire would be the most economical mode of transit, but when the messages were increased beyond a given limit, the tubes probably became most advantageous. Statistics were required to show when the tubes should supersede the electric wire. These should give the prime cost of each, the annual cost of repairs and staff, and the time occupied by each in conveying a given number of messages; so that from these facts might be deduced as a practical result that beyond a certain distance, and with a given number of messages per day, wire would answer best; and within a given distance, and beyond that number of messages per day, the tube would be the best.

Mr. D. THOMSON said the information upon the relative cost of using tubes and telegraph wires gave the results, as he understood, upon very short lengths of 200 or 300 yards. He would be glad to know whether there would still be a considerable saving if the lengths were increased, say doubled; or whether that would not have the effect of doing away with the saving said to be accomplished by the use of the tube in place of electric wires? With regard to the formulæ given by the Author of the Paper, he did not know whether the formulæ for the velocity at any given part of the circuit were correct; but there seemed to be a discrepancy between them and the formula for the mean velocity. The latter, which was the most important point, was given as the sum of the two extreme velocities, divided by 2; but that would not be the case unless the velocities were uniformly varied, which it appeared they were not; therefore, he thought the formula for the mean velocity could not be correct if the others were right.

Mr. HAWKSLEY, Vice-President, said he would offer a few observations on this subject in closing the discussion. In the first place, he would mention that Mr. Preece's formula was very different from any presented on this subject hitherto, or that was known to mathematicians with respect to the motion of fluids in close pipes. That formula was one which he was glad had been produced, because it would lead to further investigation and thinking in a new direction; but for himself, at present he was unable to recognise it, and to accept it as a true representation of the philosophical law which he believed obtained, and which he believed could not be altered by the particular arrangements which were adopted in the case of these message tubes. In the first place, it was perfectly well known that the law which regulated the flow of air and other elastic bodies through tubes did not vary essentially from the law which regulated the motion of inelastic fluids. It was known that when a perfect fluid passed through a tube with a uniform density, it mattered very little what was the nature of that fluid in respect of the law to be employed in determining its velocity. When the fluid was elastic, its density gradually diminished throughout the length of the tube; and also as a matter of course, if the density diminished there must be an amount of expansion corresponding with the reduction of the density, and there must consequently be a corresponding rapidity of motion. That consequence would, however, be affected to some extent by the amount of heat taken up in the expansion.

It was found therefore, that the pressure at the entrance must be the sum of three or four different quantities: the quantity which, for instance, represented the resistance due to a uniform inelastic fluid passing through a pipe, and the resistance which was due to the force required to put the air or gas into motion at the entrance of the pipe. Then there would be another term which was due to friction proper; the principal portion of this being due to impact; and then there would be that resistance which was either positive or negative according to the circumstances of the case, and which was due to the inclination of the tube itself. The sum of all these would be the total amount of the resistance; and from the total amount of statical resistance it was easy to obtain (approximately) the amount of power necessary to be employed to pass the plug along one of these pipes, and the velocity corresponding to that power.

This subject was investigated many years ago, at the time atmospheric railways were proposed in this country; the data were then well ascertained, and the coefficient was determined. Experiments were made to test the accuracy of the formula which had been deduced theoretically, and it was found to coincide within the nearest possible fraction; therefore, at the present time, there was not so much to learn on this subject as many persons might perhaps imagine; but still the knowledge on this subject was by no means perfect. If he said there was an error of 10 per cent. between calculation and experiment, that undoubtedly would be the outside; but that approach to accuracy ought not to be considered sufficient.

As this was a subject which had not been broached in the Institution for twenty-five years, he would give the general expression of the motion of an inelastic fluid, and explain how the motion of an elastic fluid could be deduced from the motion of an inelastic fluid. At the same time he was bound to mention that the difficulties of the subject had not been, as a matter of philosophy, at present overcome; because the integration which was necessary in the resolution of a complicated question of this kind was extremely difficult, and he believed had not yet been entirely accomplished; all the terms and all the elements necessary to be introduced bringing so many variables into the equation that a perfect integration could not, so far as he knew, be effected.

The formula which he put forward was that which was usually assumed to represent the motion of water in a smooth pipe of small and uniform diameter.

$$V = 48 \sqrt{\frac{h\,d}{l}},$$

in which h represented the pressure or head, d the diameter, and l the length of the pipe.

The coefficient was an empirical coefficient, which was to be applied in order to bring the equation into a state of fact; and it was found that this equation was just as applicable to the motion of air as it was to the motion of water. All that was necessary was to multiply the coefficient for water by the square root of the comparative density of the air; thus as water was 815 times heavier than air, if the density of water was represented by 815, and of air by 1; then

$$\sqrt{815} \times 48 = 1368$$

would be the coefficient of air of mean atmospheric density, and so as to any other comparative densities.

With regard to the passage of air through a pipe, the air was not of uniform density. The air expanded as the density diminished, and the velocity increased in the exact ratio of the expansion. The length of the pipe might be divided into parts, and the approximate density in each part being calculated, the integration might be approximately effected by Simpson's formula, which was a simple and easy expedient. He had no hesitation in saying by that means the velocity might be ascertained extremely near to the truth. But this formula was very different from that which had been presented by Mr. Preece; and though Mr. Preece's formula and his facts were worthy of all attention, as he had already said, while he accepted the observed facts, he was unprepared to accept the formula.

Mr. W. H. Preece explained that there was no material difference between Mr. Hawksley's formula and that which he had referred to. The same notation was used to express different quantities. Mr. Hawksley's formula gave the flow of volume, viz-, the discharge of air or gas in cubic feet per unit time. Mr. Preece's formula gave the flow of mass, viz., the rate of motion of unit mass in lineal feet per unit time. The one could very easily be deduced from the other.

November 21, 1871,

CHARLES B. VIGNOLES, F.R.S., President,
in the Chair;

and,

November 28, 1871,

T. HAWKSLEY, Vice-President,
in the Chair.

The discussion upon the Paper, No. 1309, "Pneumatic Despatch Tubes: the Circuit System," by Mr. Carl Siemens, was continued throughout both Meetings.

December 5, 1871.

JOSEPH CUBITT, Vice-President,
in the Chair.

The following Candidates were balloted for and duly elected:—Ernest Benedict, and Mark Hyde, as Members; Henry Adams, Stud. Inst. C.E., Edwin Clerk Allam, Emerson Bainbridge, Stud. Inst. C.E., William Borrer, *Major* James Browne, R.E., *Major* Joseph Smith Bryce, Henry Carter, Stud. Inst. C.E., Octavus Deacon Clark, *Captain* Henry Doveton, R.E., Barrow Emanuel, M.A., Walter Combermere Lee Floyd, Joseph Rake Harding, John Jurd, Edward Tiley Lambert, B.A., Edward John Lloyd, Philip Edward Murphy, Robert Augustus Oldham, Christopher Pattison, George Pullen Pocock, Stud. Inst. C.E., Thomas Tenison Ryan, William Heron Steel, Frederick William Stevens, *Major* Richard Hugh Stotherd, R.E., James Strachan, Arthur Smith Truman, William Walton Williams, Jun., Stud. Inst. C.E., George Walter Winckler, and Alfred Hope Wood, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. VII., of the Bye-Laws, had transferred Harry Pasley Higginson, Alexander McKerrow, John Birch Paddon, and William Henry Preece, from the class of Associate to that of Member.

Also, that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—William Syson Cundy, Harry Dancer, George Edmund Doorly, James Graham Doorly, Alan Grant-Dalton, George Jessop, William Stronach Lockhart, John Christie Mackay, Alexander William Moore, Alfred Eley Preston, Alphonso Raymond, Cecil Scott, and William Kitson Stent.

No. 1,307.—"On the Stresses of Rigid Arches, Continuous Beams, and Curved Structures."[1] By WILLIAM BELL, M. Inst. C.E.

THE Author, in his remarks on M. Gaudard's Paper "On Metal and Timber Arches" read at the Institution of Civil Engineers in December, 1870, described a method of constructing the curve of equilibrium for an arch unequally loaded, with continuous or discontinuous weights, or under oblique pressure.[2] The following Paper contains the application of this method to the investigation of the Stresses on Rigid Arches, Continuous Beams, and Curved Structures.

As the consideration of the voussoir arch is more simple than that of the rigid arch, it has been thought desirable to give a preliminary illustration of the method, as applied to the case of an arch of masonry subjected to oblique pressure and to the action of a passing load.

VOUSSOIR ARCH.

The arch chosen for examination is that of the Pont-y-tu-Prydd, over the river Tâfe, in the county of Glamorgan. The following particulars are taken from a description of this bridge given in the Minutes of Proceedings of the Institution of Civil Engineers, vol. v., p. 474.

The span is 140 feet, and rise 35 feet. The arch ring is of rubble masonry, of a depth of 2 feet 6 inches on the face, and not more than 1 foot 6 inches in the body of the arch. The first time the bridge was built the arch failed, by the weight of the haunches forcing up the crown. On being rebuilt, the spandrels were lightened by cylindrical openings, and the spaces between these were said to have been filled in with charcoal. It may therefore be taken as a good example of an arch of small stability.

The curves of equilibrium on different suppositions are shown on Plate 3, Fig. 1, the dotted line (*b*) being drawn as if the spandrels were filled in solid in the usual manner, and the line (*a*) corresponding to the bridge with cylindrical openings, but without any allowance for the lightness caused by the charcoal filling. It will be observed that the openings act as negative weights in changing the form of the curve of equilibrium, and bring it to coincide very nearly with the centre of the arch ring, so that the utility of thus lightening the spandrels is unquestionable. This is confirmed by an examination of the inverse problem, of finding the load at each point from the form of the curve of equilibrium, assuming it to coincide with the centre of the arch ring.

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[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxi., pp. 143-148.

The dotted black line at the right of Fig. 1 shows the line of roadway on this supposition, and the construction, which may be thus shortly explained, is indicated by the dotted lines.

Having divided the semi-arch into any number of portions, in this case ten, each of the same horizontal length, and drawn vertical lines through the points p_1, p_2, p_3, &c., the centres of these portions, draw the line C D tangential to the curve of the centre line of the arch ring at the crown, to represent the line of horizontal thrust. Since the curve of the arch ring is assumed to be the curve of equilibrium, its tangent at B will cut the line C D in a point D such that C D = D B, and this point D will be in the vertical line passing through the centre of gravity of the unknown mass of the arch between B and C.

Draw any horizontal line D′ E, and lines $D'q_1$, $D'q_2$, $D'q_3$, &c., through D′ respectively parallel to $p_1\,p_2$, $p_2\,p_3$, $p_3\,p_4$, &c.; also draw the line E F vertical, at such a distance E D′ from D′ that Eq_1, the part of it cut off by the line $D'q_1$, may be equal to the height from the soffit to the roadway at the point p_1, and will thus measure the weight of that portion of the arch acting at p_1. Then $q_1\,q_2$, $q_2\,q_3$, &c., the parts of the vertical line through E, cut off by the lines $D'q_1$, $D'q_2$, &c., will be the heights of the roadway above the soffit at the points p_2, p_3, &c., and if these be set up vertically above the soffit at the different points, the curve line connecting their upper extremities will be the required line of roadway, which, it will be observed, falls considerably below the line of the actual roadway at the part near the openings.

In drawing the above lines, the arch has been divided into portions having equal horizontal lengths, because then the weight of each portion is measured by the height from the soffit to the roadway. This supposes the density of the backing to be the same as that of the voussoirs, which is probably not far from the truth. The pressure has been considered as wholly vertical, or the backing as composed of a number of separate vertical prisms with horizontal bases, through which the pressure is transmitted to the voussoirs, the backs of which may be considered as notched in level steps, to receive the bases of the prisms.

But the material of the backing must have some amount, however small, of mobility among its particles, and the back of the arch having an inclined surface, the pressure cannot be quite vertical. In the absence of any information as to the nature of the backing, the small deviation of the pressure from verticality cannot be known, but some idea of its effect may be gained by ascertaining the nature of the change of the curve of equilibrium, on the supposition that the backing, while retaining its density, is a perfect fluid, pressing at right angles to the back of the arch.

Having divided the arch ring into portions of equal horizontal lengths, as a sufficient approximation, the whole mass of each portion may be taken as pressing at right angles to the back of the arch, with a head equal to the height between the soffit and the roadway at the centre of the division.

At any point *p*, on the left side of Fig. 1, the intersection of the vertical line through the centre of one of the divisions with the centre line of the arch ring, take $p\ s = p'\ s'$, and draw the normal line *p t*, and horizontal line *s t*. Then *p s* will represent the weight of the portion acting at *p*, *s t* its horizontal push, considered as a fluid with a head equal to *p s*, and *p t*, normal to the curve, will be the resultant of these two forces.

The horizontal forces acting at the different points are thus found, and from these, by the method of moments, the vertical height above A of the line of action of their resultant or sum can be easily ascertained. Draw M N at this height, and from the point M, where the vertical line G M through the centre of gravity of the semi-arch cuts M N, set off M N equal to the sum of the horizontal forces, and draw N O vertical and equal to the weight of the half arch. The line M O will then be the resultant of all the forces acting on the semi-arch, and will be in the direction of the normal to the curve of the arch ring, since the direction of each of the component forces is normal. The line M O will cut the horizontal line through C, the centre of the crown of the arch in some point G′, and the points G′ and A, being joined, G′ A will be the direction of the thrust at A. To find its amount, draw any vertical line *r k* equal to the weight of the half arch, and draw a horizontal line K *k* L through the point *k*. From any point G in C G′ draw G L parallel to G′ A, cutting K *k* in L, and from L draw L H parallel to G′ O, cutting C G produced in H. Then H L will be equal to the resultant M O, and G L will be the amount of the thrust at A.

To draw the curve of equilibrium, set off from H, H v_1 equal and parallel to the force acting at p_1', $v_1\ v_2$ equal and parallel to the force at p_2', and continue this construction, which, if correct, will terminate by the end of the last line drawn coinciding with the point L. This force diagram may also be made by plotting the vertical and horizontal components of the separate forces at p_1', p_2', &c., beginning at the point H. The curve of equilibrium can then be constructed by drawing from the point p_1', where the direction of the force at p_1' cuts the horizontal line C H, $p_1' z_2$ parallel to G v_1, to cut the direction of the force acting at p_2' in the point z_2; from z_2 thus found drawing the line $z_2 z_3$ parallel to G$'v_2$, to cut the direction of the force at p_3' in z_3, and continuing this construction, which will terminate by the last line drawn passing through the point A, and coinciding with A G$'$.

The supposition of fluid backing shows a considerable alteration of the curve of equilibrium, and indicates the tendency of the obliquity of the pressure of ordinary backing to make this curve deviate towards the extrados at the haunches of the arch. In the present instance, the effect of the lightness of the charcoal filling at the openings would be to cause a deviation in the opposite direction; so that, in all probability, the true curve is represented by the line (*a*), and the arch has almost all the stability which an arch ring of such small depth is capable of.

In order to obtain a somewhat more definite idea of the stability, it is not difficult to ascertain what change will take place in the curve of equilibrium when a load of known weight passes over the bridge.

It will be explained hereafter that the effect of a load is greatest when it acts about midway between the crown and the abutment, and that the curve of equilibrium for a load considered as the only force acting on the arch is represented by two straight lines, one of which passes through the crown of the arch and the centre of the abutment farthest from the load, and the other line passes through the abutment nearest to the load, and the point where the vertical line through the load cuts the first-mentioned line.

Further, by Equation (13), page 89, the curve of equilibrium of the unloaded arch will by the loading be altered at every point through a space equal to the vertical distance between the neutral line of the arch and the line of equilibrium of the load, this distance being reduced in the ratio of the horizontal thrust of the load to that of the arch and load.

Draw, therefore, the vertical line *c d* through the load supposed to act at *c*, cutting B C produced in *d*, and join *d* A: *d* A, *d* B will be the curve or lines of equilibrium of the load alone, and if *a b* be drawn vertically, and equal to the load, and *d g* horizontally to cut *a b* in *g*, *d g* will be the horizontal thrust caused by the weight alone. To reduce this to numerical quantities, if in the present instance a load of 5 tons be supposed to act in the line *c d*, the horizontal thrust will be 2·4 tons.

The weight of the semi-arch may be taken at 415 tons, and its horizontal thrust estimated by scale from Fig. 1 at 309 tons.

If the vertical ordinates between the curve of the arch and lines of equilibrium of the weight be reduced in the above-mentioned ratio, and superposed on the curve of equilibrium of the arch itself, the alteration of the curve at the point under the weight will, when reduced in the above-mentioned ratio, be 28·5 feet × $\frac{2\cdot4}{311\cdot4}$, or say 3 inches. In like manner, the depression in the middle of the opposite semi-arch will be 10 feet × $\frac{2\cdot4}{311\cdot4}$, or say 1 inch.

When a weight of 5 tons, therefore, acts on the arch midway between the crown and the abutment, the curve of equilibrium will be raised 3 inches at the part where the weight acts, and depressed 1 inch at the middle of the opposite semi-arch.

As the former deviation is nearly $\frac{1}{6}$th of the thickness of the arch ring, the compression per square inch will, by the remarks on Equation (6 *a*) page 74, as compared with the uniform compression if the curve of equilibrium were central, be doubled at the extrados, and reduced to zero at the intrados of the arch.

Taking the depth of the arch ring at 20 inches, and its width at the crown at 14 feet 6 inches, the uniform compression there caused by the horizontal thrust of 309 tons is nearly 13 tons, and at the point where the weight is supposed to act 14 tons per square foot.

During the passage of a load of 5 tons over this bridge, therefore, the extrados at the point under the weight would be sustaining a compression of 28 tons per square foot. This result would be to some extent mitigated by the pressure from the weight being conveyed to the arch through the backing, and thus acting on a surface of some extent, instead of a point as supposed.

Friction would not modify the curve of equilibrium, but it would be of service in preserving the stability of the arch, if in any part the workmanship were so faulty that the joints of the arch were inclined to the normal at any angle less than the angle of friction.

The cohesion of the mortar, after it had properly set, like the elastic forces of a rigid arch, would be brought into action if the curve of equilibrium deviated from the centre line of the arch ring by more than $\frac{1}{6}$th of its depth. There would then be a tensile stress on the opposite edge of the arch ring, and the cohesion of the mortar would resist this, and diminish to some extent the compression at the other edge.

The nature of the alteration of the curve of equilibrium, on the supposition of the fluidity of the backing, shows that the practice sometimes adopted, of coating the back of an arch with puddle, may be useful in segmental arches of large rise and level roadway, besides making them watertight. In these, the curve of equilibrium near the abutments descends below the curve of the arch ring, and the partial fluidity of the backing would tend to raise the curve and increase its curvature at these points. There would also be less horizontal thrust against the abutments, since the thrust at A is altered from A G to A G′ by the supposition of the fluidity of the backing. There would thus be a tendency to diminish any injurious stress on the arch and abutments until the mortar had properly set.

Rigid Arch.

The investigation of the stresses of a rigid arch has hitherto been a subject of considerable difficulty, owing to the intricate nature of the mathematical analysis it is necessary to employ.

The circular rib has been examined by Mr. Wilfrid Airy, Assoc. Inst. C.E., in his recent treatise on "Iron Arches," and M. Gaudard has given, in the Appendix to his Paper on "Metal and Timber Arches" (Min. of Proc. Inst. C.E., vol. xxxi., p. 98), a solution of the case of a circular rib of varying section. The subject has also been investigated generally, and applied in some detail to the case of the parabolic rib, by Dr. Rankine, in his work on Civil Engineering. The results of these authors being expressed in algebraical formulæ, the labour of applying them numerically to trace the variation of stress from point to point is considerable. Still, before the transverse sections of arch ribs can be proportioned to the stresses coming upon them, a knowledge of this variation is indispensable.

In experiments on the strength of materials, it is found that there are considerable differences in the breaking weights of specimens of the same kind of material, although the dimensions of the specimens are identical. This fact, which makes it necessary to employ a large factor of safety in engineering constructions, renders it unnecessary to solve questions of stress with minute accuracy, and the graphic method of solution is generally a sufficient approximation in practice. From the assistance which this method affords in the treatment of voussoir arches by means of the curve of equilibrium, it occurred to the Author that if it could be applied to the investigation of rigid arches, an equal facility of solution would be obtained.

It will now be shown that the method can be applied, and that the stresses at every point of an arched rib admit of being represented by a diagram, so that their changes from point to point can be readily ascertained. Some questions, also, such as those where the form of the rib differs from the circle and parabola, and where the pressure is oblique, which would be almost intractable by analysis, can be readily solved by this method.

The curve of equilibrium of an arch is so constructed, that the pressure at any point in the direction of the curve is combined with the external force acting there. The resultant pressure is in the altered direction of the curve beyond the point. By this construction it will be seen, that the curve is the locus of the resultant of all the outward forces, and since the moment of a resultant is equal to the sum of the moments of its component forces, the 'bending moment,' or transverse stress at any point, is equal to the pressure in the direction of the tangent to the curve of equilibrium, multiplied by the perpendicular on this tangent, from the point in question. This moment tends to bend the rib in different directions, according as the curve of equilibrium is above or below the neutral line of the rib, or line passing through the centres of gravity of its transverse sections.

A general idea of the nature of the stresses may be given by Figs. A and B, page 65, premising, as will be shown hereafter, that a force acting parallel to the neutral line, at a given perpendicular distance from it, may be considered as equivalent to a force of the same amount acting in the neutral line, together with a couple, whose moment is the force multiplied by the given perpendicular distance from the neutral line.

The absolute amounts of the stresses may be ascertained by Equation (6 *a*), page 74.

1st. The rib is subject to a general compression throughout its whole length, to the same extent as if it were a voussoir arch, and the curve of equilibrium coincided with its neutral line. This may be represented by a force F (Fig. A) uniformly distributed over the area of section, and giving rise to the equal forces per square inch represented by the lines *f*, *f*, *f* acting at the different points of this area.

2nd. The rib is subject also to the stress caused by the bending moment. When this acts so as to increase the curvature, in which case the curve of equilibrium descends below the neutral line of the rib, its state of stress may be represented as in Fig. A.

Any transverse section A B of the rib A B C D is in the same

Fig. A.

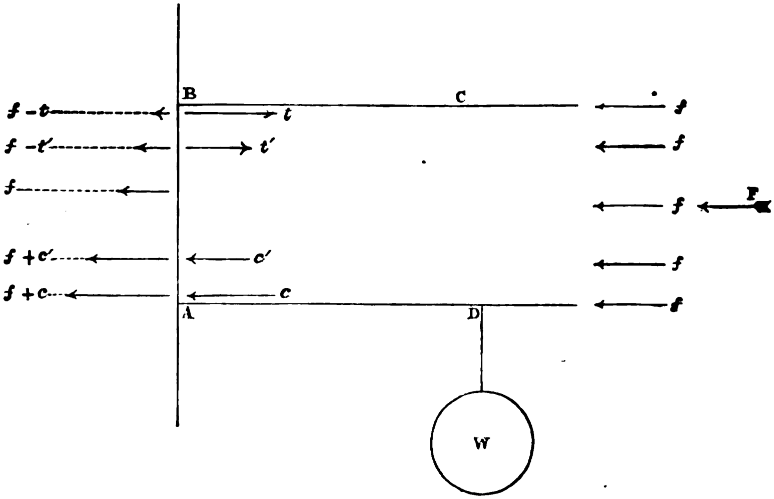
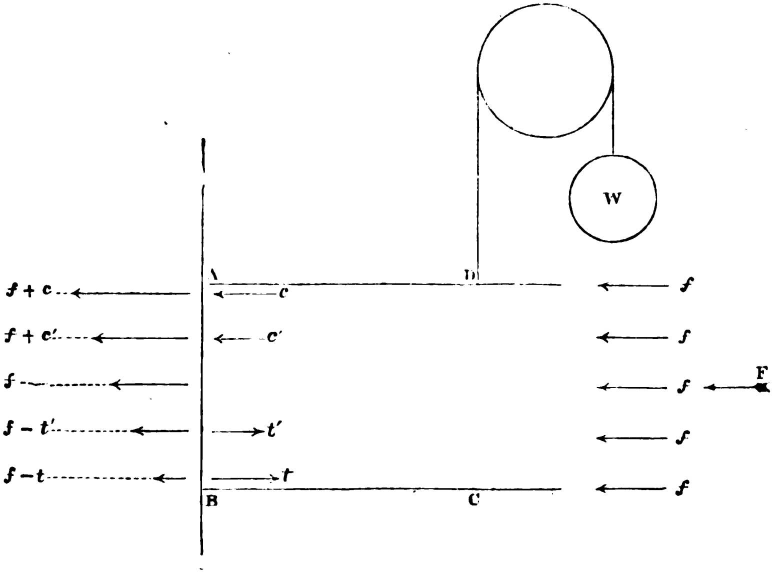

f − t
f − t′
f
f + c′
f + c
B
C
A
D
t
t′
c′
c
f
f
f
f
f
F
W

Fig. B.


W
f + c
f + c′
f
f − t′
f − t
A
D
c
c′
t′
t
B
C
f
f
f
f
f
F

condition as if this section were fixed in a wall, and acted on by the force F, and also by a weight W at a leverage A D, W × A D being equal to the bending moment, and the total stress at any point is the algebraical sum of the stress due to the action of F, and of that due to the bending moment. This latter will excite tensile forces at the top, and compressive forces at the bottom of the rib, which forces per square inch may be represented on the diagram, Fig. A, by the lines t, t', c', c. The result of the actions of F and W together is that the stresses at the top are represented by the lines $f - t$, $f - t'$, &c., and at the bottom by $f + c$, $f + c'$, &c.

In like manner, at those points of the rib where the bending moment tends to diminish the curvature, and the curve of equilibrium is above the neutral line of the arch rib, the transverse section A B is in the state represented by Fig. B, the weight W acting upwards instead of downwards, as in Fig. A.

Here the tensile forces are at the bottom, and the compressive forces at the top of the rib, the forces resulting from the action of both F and W being $f + c$ at the top, and $f - t$ at the bottom.

The values of c and t being independent of f, $f - t$ may become either zero or negative; that is, the part of the rib to which $f - t$ corresponds may either have no strain or be in tension, according as the tensile force excited at the outer surface by the bending moment is equal to, or greater than, the uniform compressive force f caused by the action of F.

In the state represented by Fig. A, the bending moment will in what follows be considered as positive, or tending to increase the curvature of the rib, and in the state represented by Fig. B as negative, or tending to diminish the curvature.

General Conditions of Equilibrium.

For the voussoir arch, the transverse stress which could be overcome by the cohesion of the mortar being so small as not to be worth considering, the curve of equilibrium has generally been assumed to pass through the centre, or, at all events, within the substance of the arch ring at the crown, and its position there determines the horizontal thrust.

But the mode of constructing the curve of equilibrium is independent of its passing through any particular points, either at the crown or at the springing. The points there may be shifted either upwards or downwards, and the curve can be constructed in exactly the same manner, but its figure will be altered by varying the position of these points.

It is necessary to explain the meaning of these changes of position.

When the vertex of the curve at the centre of the crown is raised above the neutral line, it appears by the previous remarks as to the moment of the resultant, that a bending moment will exist there, tending to diminish the curvature of the rib. The horizontal thrust will also be diminished, since it acts at a greater vertical distance from the abutment.

Supposing the vertex of the curve of equilibrium to recede upwards from the crown of the arch, the horizontal thrust will continue to diminish, but its leverage to increase. The bending moment at the crown of the arch may therefore be finite, even when the vertex recedes to an infinite distance. The condition, in fact, then corresponds to that of a girder resting on level abutments, and incapable of supplying any horizontal thrust.

On the other hand, if the vertex of the curve descends below the crown of the arch, the bending moment there becomes positive, and tends to increase the curvature of the arch rib. The horizontal thrust is also increased, the weight of the arch remaining the same. When the horizontal thrust is finite, but the weight and rise of the arch are both equal to zero, then the arch becomes a horizontal pillar.

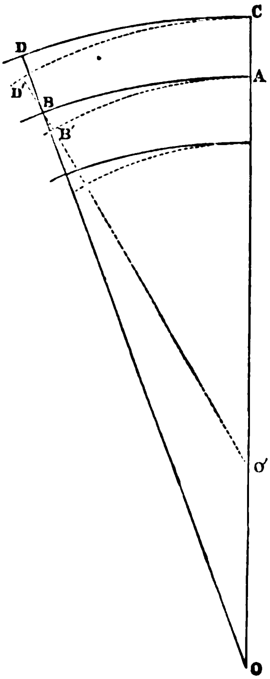
When the springing points of the curve are shifted, so that the curve does not pass through the centre of the arch ring at the abutments, a bending moment, of an amount determined by the alteration of the springing points, exists at the abutments, and the horizontal thrust is also altered.

By thus shifting the position of the vertex, or of the springing points, or both, of the curve of equilibrium, the horizontal thrust, and the transverse stress at the crown and springing may be indefinitely varied, and may be made to satisfy the conditions of a rigid arch with the feet kept from spreading, so that the span is invariable, or of a rigid arch with the ends 'fixed,' or "*encastré*."

What these conditions are will now be explained; but it is necessary to offer some elementary remarks as to the effect of transverse stress on the curvature of an arch rib.

In Fig. C, if A B be a small portion of the neutral line of an arch rib, its centre of curvature being at O, when it is under transverse strain, the line A B will change to some other position, as A B′, the centre of curvature changing to O′. And a concentric length C D, distant from the neutral line by the length C A, will become curved into C D′, and will be elongated or contracted according as the point C is farther from or nearer to the centre of curvature than the point A.

Fig. C.



The ratio of this change of length C D′ − C D to the primary length C D measures the force exerted by the fibre C D. If a be the reciprocal of the fraction which expresses the extension of the unit of length of the material by a force of 1 ton per square inch, then $a \cdot \frac{CD' - CD}{CD}$ will be the force exerted by C D considered as having a sectional area of unity. And if the transverse section of the rib be divided into a number of small portions, each having an area = Δ A, A being the total area, and the area of C D be one of these portions, then $a \cdot \frac{CD' - CD}{CD} \cdot \Delta A$ will be the force exerted by C D, considered as having the area Δ A.

But $CD - AB : AB :: CA : AO$

or $CD - AB = AB \frac{CA}{AO}$

and $CD' - AB' : AB' :: CA : AO'$

or $CD' - AB' = AB' \frac{CA}{AO''}$.

and deducting, since A B = A B′,

$$CD' - CD = AB\left(\frac{CA}{AO'} - \frac{CA}{AO}\right).$$

Or, taking the limit of $\frac{AB}{CD} = 1$,

$$\frac{CD' - CD}{CD} = CA\left(\frac{1}{AO'} - \frac{1}{AO}\right).$$

The force exerted by C D is, therefore, in tons,

$$a\left(\frac{1}{AO'} - \frac{1}{AO}\right) CA \cdot \Delta A,$$

and is thus proportional to the difference between the reciprocals of the radii of curvature A O, A O′.

The moment of this force with respect to the neutral axis is found by multiplying it by C A, or is $a\left(\frac{1}{\mathrm{A\,O'}} - \frac{1}{\mathrm{A\,O}}\right)\mathrm{C\,A}^2 \cdot \Delta\,\mathrm{A}$.

Calling M the moment of the whole sectional area,

$$\mathrm{M} = a\left(\frac{1}{\mathrm{A\,O'}} - \frac{1}{\mathrm{A\,O}}\right) \cdot \Sigma\,\mathrm{C\,A}^2 \cdot \Delta\,\mathrm{A}.$$

The last factor $\Sigma\,\mathrm{C\,A}^2 \cdot \Delta\,\mathrm{A}$, or the sum of all the small portions of the area, each multiplied by the square of its distance from the neutral axis, is generally represented by I.

Hence,

$$\mathrm{M} = a\,\mathrm{I}\left(\frac{1}{\mathrm{A\,O'}} - \frac{1}{\mathrm{A\,O}}\right) \quad . \quad . \quad . \quad . \quad . \quad (1)$$

But calling t_0 the tension or compression per square inch at the outer surface of the rib, considering C D as this outer surface, and putting $\mathrm{C\,A} = k_0$

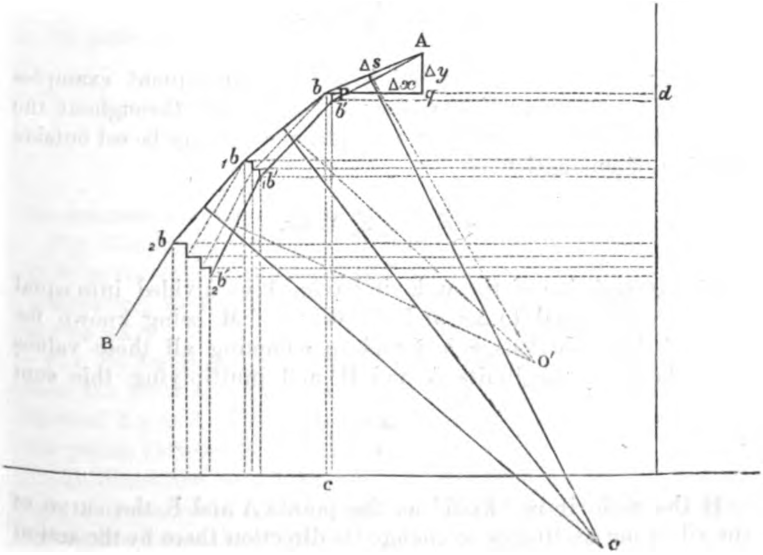
$$\frac{\mathrm{C\,D'} - \mathrm{C\,D}}{\mathrm{C\,D}} = \frac{t_0}{a} = k_0\left(\frac{1}{\mathrm{A\,O'}} - \frac{1}{\mathrm{A\,O}}\right);$$

and, by combining this with (1),

$$\mathrm{M} = \frac{t_0}{k_0} \cdot \mathrm{I} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

This moment M, representing the moment of the elastic forces of the rib, is at every point in equilibrium with the moment of the outward forces.

Fig. D.



In Fig. D, let $A\,b = b\,{}_1b = {}_1b\,{}_2b$, &c., each of these being equal to Δs, be a polygon forming the chord lines of a portion of the neutral curve of an arch rib before strain, the centre of curvature being O.

When the rib is strained, the polygon will change into some other form as $A\,b'\,{}_1b'$, &c., the centre of curvature changing to O′.

If $\Delta s = A\,b$ subtend an angle θ at the centre O before strain, and an angle θ' at the centre O′ after strain, then

$$\theta = \frac{\Delta s}{A\,O} \qquad \theta' = \frac{\Delta s}{A\,O'}$$

and

$$\theta' - \theta = \Delta s\left(\frac{1}{A\,O'} - \frac{1}{A\,O}\right)$$

$$= \Delta s\,\frac{M}{a\,I}$$

by equation (1).

Since lines drawn through the middle parts of these chords, and perpendicular to them, meet in the centre of curvature, the angle $\theta' - \theta$ is equal to the angle $b'\,A\,b$, and expresses the change of direction of Δs after the rib has been strained.

The total change of direction of the tangent to the curve of the rib between the points A and B will therefore be the sum of all the values of $\theta' - \theta$ between these limits. Calling this change of angle Θ,

$$\Theta = \Sigma_A^B \frac{1}{a\,I} M\,\Delta s.$$

And if, as will be supposed in all the subsequent examples except the last, the section of the rib be uniform throughout the length, the value of I will be constant, and it may be set outside the sign of summation, or

$$\Theta = \frac{1}{a\,I}\,\Sigma_A^B\,M\,\Delta s.$$

The neutral line of the arch rib having been divided into equal lengths, each equal to Δs, and the value of M being known for each of these portions, Θ is found by summing all these values of M between the limits A and B, and multiplying this sum

by

$$\frac{\Delta s}{a\,I}.$$

If the arch rib be 'fixed' at the points A and B, the curve of the rib is not at liberty to change its direction there by the action of the outward forces, and therefore in this case $\Theta = 0$; or, if the rib be fixed at the ends, the condition

$$\Sigma_A^B (M) = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

must be fulfilled, and the curve of equilibrium must be so chosen as to satisfy this condition.

Further, the length of the line $b\,b'$, which measures the change in the position of the end of Δs, is $\Delta s (\theta' - \theta)$,

or $$b\,b' = \Delta s^2 \frac{M}{a\,I}.$$

Referring the curve to rectangular axes, and calling $b\,q = \Delta x$, $A\,q = \Delta y$, the change $b\,b'$ may be considered as made up of the horizontal change $b\,p$, and the vertical change $b'\,p$.

By similar triangles, $b\,b'$ being small,

$$b\,p = b\,b' \frac{\Delta y}{\Delta s}$$

$$= \frac{1}{a\,I} M \Delta s \Delta y$$

$$b'\,p = b\,b' \frac{\Delta x}{\Delta s}$$

$$= \frac{1}{a\,I} \cdot M \cdot \Delta s \Delta x.$$

Therefore if h and v be the horizontal and vertical displacements of the point B, I being supposed constant,

$$h = \frac{1}{a\,I} \Sigma \Sigma M \Delta s \cdot \Delta y \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$v = \frac{1}{a\,I} \Sigma \Sigma M \Delta s \cdot \Delta x \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

the summations being made between the limits A and B.

Fig. D is intended to show the building up of the displacement at B, by the displacements at b, ${}_1b$, ${}_2b$, &c.

Referring to Equation (4), the double summation may be made in two ways:

(1). By forming for each point b the sum of all the values of M from the limit A up to this point, multiplying this sum by the value of Δy at the point, and summing up these products for all the points between A and B.

(2). Since the sum $\Sigma \Delta y = y = b\,c$ for each point, the summation may be made by forming the sum $\Sigma (M\,y)$ or $\Sigma (M \cdot b\,c)$ between the limits A and B.

The latter, which is that used in Mr. W. Airy's treatise, is the easier one, and is better adapted to the arrangement, here followed, of considering the forces on each element of arc, and the bending moment M, to act at the centre of the elementary arc.

It consists, therefore, of the following process:

Having found the values of M for each part Δs, multiply each value of M by the ordinate bc at the point to which it corresponds, and add all these products together between the limits A and B.

If the feet of the arch rib be kept from spreading, the horizontal displacement is zero, and the curve of equilibrium must satisfy the condition

$$\Sigma (M \cdot bc) = 0 \qquad . \quad . \quad . \quad . \quad . \qquad (6)$$

between the limits of the ends of the arch rib.

And if the arch rib is also fixed at the abutments, so that not only the span is invariable, but the angle contained between the tangents to the curve at each abutment is also invariable, the conditions (3) and (6) must coexist,

or
$$\Sigma (M) = 0$$
$$\Sigma (M \cdot bc) = 0.$$

In this case, the curve of equilibrium generally does not pass either through the crown or the ends of the arch rib, but the vertex and springing points of the curve will require to be altered until the two conditions are satisfied.

These conditions also co-exist if the rib be fixed in direction at one end, and the other end be fixed in position, though not in direction, so that the span remains invariable. The curve of equilibrium will pass through that end of the rib which is only fixed in position, the bending moment being there equal to zero, and the vertex, and springing point of the curve at the other end of the rib, will require to be raised or lowered until the above conditions are satisfied.

Another arrangement, which is virtually a pair of cantilevers meeting in the middle of the span, is where the rib is fixed at the abutments and hinged at the crown. In that case, the curve of equilibrium must pass through the crown, and the springing points be raised so as to satisfy the condition

$$\Sigma (M \cdot bc) = 0.$$

Hitherto the section of the rib has been considered as uniform throughout the whole length. If it is desired to consider the section as changing from point to point, the quantity I which has been taken as constant must be replaced under the sign of summation, or the values of $\frac{M}{I}$ must be used instead of M in satisfying the conditions.

Conditions (3) and (6) will then be replaced by

$$\Sigma\left(\frac{M}{I}\right) = 0$$

$$\Sigma\left(\frac{M}{I} \cdot bc\right) = 0.$$

And the value of M for each length Δs must be divided by I before entering it in the sum which is to be made equal to zero between the limits.

To construct a rib with sections at each point proportioned to the stresses, a uniform sectional area may be assumed as a first approximation. The curve of equilibrium being then drawn and the stresses determined, the rib may next be assumed to have sections proportioned to these stresses as a second approximation.

The curve of equilibrium being again drawn, will differ slightly from the previous one, inasmuch as $\frac{M}{I}$ has been used in fixing it instead of M. The stresses being then determined, another approximation to the correct sections will be obtained by making them proportioned to the altered stresses, and will probably be near enough for practical purposes, but the approximation may be carried as far as thought necessary.

Having determined the conditions which the curve of equilibrium must satisfy, it is not difficult to construct the curve after a few trials by the method mentioned at the beginning of this Paper. The value of the bending moment or transverse stress at any point thus becomes known.

Effect of Bending Moment, and Amount of Total Stress.

In order to appreciate the effect of the addition of a bending moment on the stress of an arched rib, let F be the resultant pressure in the direction of the tangent to the curve of equilibrium, which may, for the purpose of this illustration, be supposed parallel to the tangent to the neutral line of the rib, or the uniform compressive force if the rib be in the state of the voussoir arch (Figs. A and B); and let p be the perpendicular let fall on the direction of F at the point of the rib to which F corresponds. The addition of two forces $+ F'$ and $- F'$, each equal in amount to F, but acting in opposite directions, at that point of the neutral line of the rib to which F corresponds, the directions being coincident with the tangent to the neutral line, will not disturb the equilibrium; and F may be considered as equivalent to $+$ F, $+$ F′ and $-$ F′. The effect of $+$ F and $-$ F′ is to cause a bending moment, and, since $F' = F$, the effect of the remaining force $+$ F′ is to cause a direct compression of the rib, of the same amount as if F acted in the neutral line. The bending moment

$$M = F p;$$

and if I is put equal to $A q^2$, where A is the area of cross section and q its radius of gyration in reference to the neutral axis, then by formula (2),

$$F p = \frac{t_0}{k_0} A q^2,$$

and

$$t_0 = \frac{F}{A} \cdot \frac{k_0 p}{q^2}$$

for the tension or compression per square inch arising from the action of the bending moment, or what has been called the forces t and c in Figs. A and B.

The total stress being that due to the direct action of F and a couple represented by $F p$, the rib will sustain a direct compression from F as well as the force t_0. This compression, considered as uniformly distributed over the area A of section, will give a compression per square inch of $\frac{F}{A}$, and the total stress will be

$$\frac{F}{A} + \frac{F}{A} \cdot \frac{k_0 p}{q^2};$$

or, since $\frac{F}{A}$ is what has been called the force f in Figs. A and B,

$$\text{Total stress} = f\left(1 + \frac{k_0 p}{q^2}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6a)^1$$

the positive sign representing compression, and the negative sign tension.

If p be taken $= k_0$, that is, if a point in the arch rib be considered for which the curve of equilibrium is approximately

---

[1] This formula may be deduced from the usual considerations in regard to elasticity, in such a manner as to lead to some interesting conclusions.

Let A B C D in the annexed Fig. be a portion of the rib or solid acted on by the force F, the plane A B C D passing through G the centre of gravity of the coincident with the outer surface, the above value of the stress becomes

$$f\left\{1+\left(\frac{k_0}{q}\right)^2\right\}.$$

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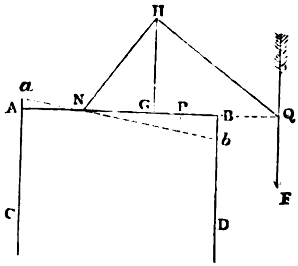
area of cross section, and Q F the direction of the force F. Also, let A B perpendicular to Q F be the intersection of A B C D, and the plane of cross section.



The area of cross section of the solid is supposed to be perpendicular to the plane of the paper, and of any form whatever. Let Q be the point where the line of direction of the force F cuts A B produced, and N the point of separation between the compressed and extended parts of the solid, A B C D representing the form of a portion before strain, and $a\,b$ C D its form when under the action of the force F.

Put $GN = n$, $GB = k_0$, or $NB = n + k_0$, $GA = k_1$, $GQ = P$, and let A be the area of cross section, and S the compressive force per square inch at the point B.

Then for any point P, if P N be put $= x$, and y be the breadth of the area of cross section of the solid at this point P, measured perpendicularly to the plane of the paper, the elementary area of cross section there will be $y\,dx$, and the force exerted by the portion of the solid to which this elementary area corresponds, will be $\frac{S}{n+k_0}\,.\,x\,.\,y\,dx$. The sum or integral of all these forces is equivalent to the force F. Hence

$$F = \int_{-k_1}^{k_0} \frac{S}{n+k_0}\,.\,x\,.\,y\,dx.$$

The variable part $x\,.\,y\,dx$ of the second side of this equation expresses the moment of the elementary area with respect to the point N, and since the sum of the moments of the elementary parts of an area is equal to the moment of the whole area applied at its centre of gravity,

$$\int_{-k_1}^{k_0} x\,.\,y\,dx = A\,n\,;$$

$$\text{and } F = S\,A\,\frac{n}{n+k_0}.$$

The moment of the force of the elementary area, or its effort to turn the system round N, is $\frac{S}{n+k_0}\;x\,.\,y\,dx\,.\,x$. The sum of these moments is equivalent to the moment of the force F. Hence

The value of $\frac{k_0}{q}$ depends on the form of cross section of the rib; but there are some leading types of section for which this ratio is readily determined.

(1). For a thin box or I-shaped girder $\left(\frac{k_0}{q}\right)^2$ may be taken as

---

$$F(p+n) = \int_{-k_1}^{k_0} \frac{S}{n+k_0} \, . \, x^2 \, . \, y\, d\, x.$$

But the variable part $x^2 \, . \, y\, d\, x$ is the moment of inertia of the elementary area with respect to the point N, and the integral of this, by a well-known theorem, is equal to $A\,(q^2 + n^2)$, where q is the radius of gyration of the area A with respect to its centre of gravity G. Hence

$$F(p+n) = \frac{S}{n+k_0} A \, . \, (q^2 + n^2);$$

and dividing this equation by the foregoing, and reducing, there results $p\, n = q^2$. From this it follows that the point N is so related to the point Q, that drawing the line G H through G perpendicular to A B, and making the length G H $= q$, if H and Q be joined, and H N be drawn at right angles to H Q, the point N, where H N cuts A B, will be the boundary between the compressed and extended parts of the solid.

The above value of F gives

$$S = \frac{F}{A} \, . \, \frac{n+k_0}{n},$$

or the total stress S at the outside surface B is equal to the uniform stress $\frac{F}{A}$ multiplied by the ratio $\frac{N\,B}{N\,G}$. Calling X the total stress at the point P, and putting $n + z = x$, or $z =$ G P, then $n + k_0 : n + z :: S : X$. Combining this with the above value of S,

$$X = \frac{F}{A} \, . \, \frac{n+z}{n},$$

or the total stress at any point is equal to the uniform stress $\frac{F}{A}$, multiplied by the ratio $\frac{N\,P}{N\,G}$. Making $z = 0$, or for the point G,

$$X = \frac{F}{A},$$

which shows that whatever may be the stresses on the other points the stress at the centre of gravity of the cross section is always equal to the force F divided by the area of cross section, or is the same as if the force F acted in the neutral line H G.

Substituting $\frac{q^2}{p}$ for n in the above general value of X,

$$X = \frac{F}{A}\left(1 + \frac{p\, z}{q^2}\right),$$

and making $z = k_0$, the result is Equation (6 a).

approximately = 1, and the stress therefore will be $f(1+1)$ or $2f$; that is, the stress f is doubled at the point where the curve of equilibrium touches the outer surface of the rib, and, writing $-k_0$ for k_0 (see Note to Eq. (6*a*)), $f(1-1)$, or zero, at the point in the opposite surface.

(2). For a thin circular or elliptical tube, $\frac{k_0}{q}$ is nearly = $\sqrt{2}$, and $\left(\frac{k_0}{q}\right)^2$ nearly = 2. For this form of section, therefore, the uniform stress f is tripled at the point where the curve of equilibrium coincides with the outer surface of the rib, and there is a force $f(1-2)$ or $-f$, or a tensile force equal to f, acting at the other surface of the rib.

(3). For a solid rectangular form of cross section $\frac{k_0}{q}$ is equal to $\sqrt{3}$, and $\left(\frac{k_0}{q}\right)^2 = 3$, and for this form the uniform compressive force is quadrupled, at the one surface of the rib, and there is a tensile force, of $f(1-3)$ or $2f$, at the other surface.

(4). For a circular or elliptical solid bar, $\frac{k_0}{q}$ is equal to 2, and $\left(\frac{k_0}{q}\right)^2 = 4$. For this form, the uniform compressive force is quintupled at one surface of the rib, and there is a tensile force of $f(1-4)$, or $3f$, at the other surface.

It will be obvious from these examples that the first-mentioned section is much better fitted for resisting this kind of stress than any of the others.

The general conditions of equilibrium having been explained, the action of vertical forces will be first examined.

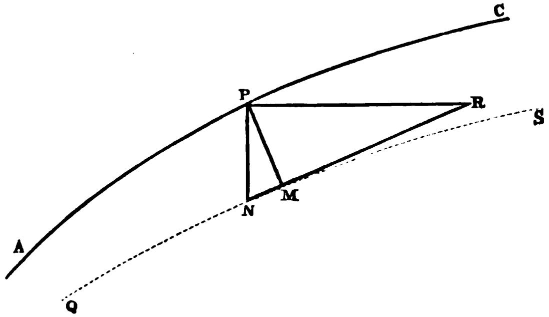
Vertical Forces.

If P, Fig. E, be any point in an arch rib of which the neutral line is A P C, the curve of equilibrium Q S, and P M the perpendicular let fall from P on the direction of the resultant, then the bending moment, as already explained, is

$$M = F \times PM.$$

Draw P N vertical, cutting the curve of equilibrium in N, R N tangential at this point N, and P M perpendicular to R N, also P R horizontal cutting R N in R.

Fig. E.



Calling H the horizontal thrust,

$$F : H :: R N : R P;$$

and by similar triangles,

$$P M : R P :: P N : R N.$$

Combining these proportions,

$$F \times P M = H \times P N.$$

Or, since in the case of vertical pressures the value of H is uniform throughout the curve, the value of M is measured simply by the length of the vertical line P N between the neutral line of the rib and the curve of equilibrium.

The conditions of equations (3) and (6) are therefore simplified.

If the rib be considered as rigid, and the ends kept from spreading, the condition to be satisfied is (see Fig. F)

$$\Sigma (P N \times P Q) = 0.$$

If the rib is also 'fixed' at A and B, the conditions are

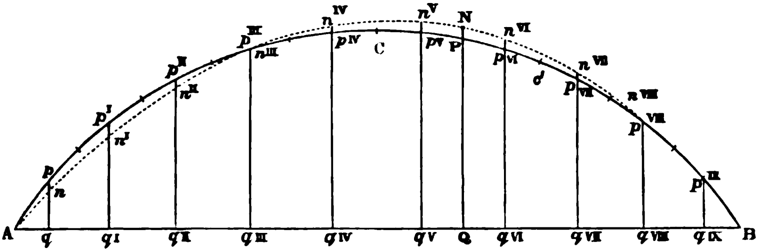
$$\Sigma (P N) = 0$$

$$\Sigma (P N \times P Q) = 0.$$

The process of construction is therefore as follows (Fig. F):

Having divided the neutral line of the arch rib into equal portions, draw vertical lines through the centres, p, p', p'', &c., of the divisions, which will cut the base line, or line joining A and B, in the points q, q', q'', &c. Also draw an approximate curve of equilibrium, which will be cut by these verticals in the points n, n' n'', &c.

Fig. F.


n^{IV}
n^{V}
N
p^{III}
n^{VI}
p^{IV}
C
p^{V}
P
n^{III}
p^{II}
p^{VI}
n^{VII}
d
n^{II}
p^{VII}
n^{VIII}
p^{I}
n^{I}
p^{VIII}
p
n
p^{IX}
A
q
q^{I}
q^{II}
q^{III}
q^{IV}
q^{V}
Q
q^{VI}
q^{VII}
q^{VIII}
q^{IX}
B

Then, if the rib be considered as rigid, with the points A and B kept from moving sideways, the curve of equilibrium must be such that between the points A and B,

$$p\,n \times p\,q + p'\,n' \times p'\,q' + p''\,n'' \times p''\,q'' + \&c. \ldots = 0.$$

That is, those products where the point n is above p, as at n^{IV}, n^{V}, &c., must balance the products where n is below p, as at n, n^{I}, &c. By satisfying this condition, the bending moments which increase the curvature and span will exactly neutralize those which diminish the curvature and span, so that the span will be unaltered. It is not difficult to find the correct curve of equilibrium after a few trials. The values of $p\,n$ and $p\,q$ can be measured by scale from the diagram, and a sliding rule will be found useful in obtaining the products. In the figure, near the vertex, where the bending moments $p^{\text{IV}}\,n^{\text{IV}}$, &c., are multiplied by the larger lengths $p^{\text{IV}}\,q^{\text{IV}}$, these products are more effective in the summation than at the haunches, where the lengths $p\,q$ are shorter, and thus the area between the two curves for that part where the neutral line of the rib is above the curve of equilibrium will require to be smaller than for the part where it lies below.[1]

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[1] Major Browne, R.E., has suggested that, in order to avoid drawing a number of trial curves, the curve of equilibrium may be made to pass accurately through any given point by the use of proportional compasses. Suppose the given point to be N′, above or below N, see Fig. F; then, having drawn the trial curve which passes through N, the curve which passes through N′ will have the ordinate Q N altered in the ratio Q N′ : Q N; and since any other ordinate, as $q\,n$, will be altered in the same proportion, this may be done by setting the compasses to the ratio Q N′ : Q N; or, if straight lines A N, A N′ be drawn from A through N and N′, for any two points at the same level, one point on the straight line A N, and the other on the trial curve which passes through N, the distance between the lines A N, and A N′, measured vertically, is equal to the distance, also measured vertically, between the curve which passes through N, and that which will pass through N′.

When the arch rib is also fixed in direction at A and B, the curve of equilibrium must be so taken that between these points, due regard being had to the signs,

$$p\,n + p'\,n' + p''\,n'' + p'''\,n''' + \&c. \ldots = 0,$$

and

$$p\,n \times p\,q + p'\,n' \times p'\,q' + p''\,n'' \times p''\,q'' + \&c. \ldots = 0$$

Generally, in order to satisfy these two conditions, the springing points of the curve of equilibrium must be different from A and B, and will require to be shifted vertically.

Roughly speaking, the first condition implies that the areas above and below the neutral line of the rib approximately balance one another. A curve being drawn which will nearly satisfy this condition, the curve can then be turned round the points midway between the point of its greatest separation from the neutral line of the rib and the ends A and B, until the second condition is also satisfied.

Taking, for example, the circular rib of 120° examined in Mr. W. Airy's treatise on "Iron Arches," the results from the method now explained may be compared with those arrived at by mathematical investigation.

Fig. 2 (Plate 3) represents the rib acted on only by its own weight, considered as uniform per foot run of the rib; Fig. 3, where a load a little less than the weight of the rib, in the proportion of the chord of the arc of 60° to the arc itself, acts at the centre of the crown; and Fig. 4, where this weight acts at 30° from the crown.

In these figures, the full line represents the line of the arch rib; the dotted line (*a*) corresponds to the curve of equilibrium of the voussoir arch, or rib hinged at the crown; the dotted line (*b*) to the rigid arch, with the ends kept from spreading; and the dotted line (*c*) to the rigid arch, with the ends 'fixed.'

In the following mathematical investigation of the voussoir arch, and arch with the ends fixed, the method used by Mr. W. Airy is adhered to as closely as possible, for the sake of comparison; and a short recapitulation of that method may be made for the better understanding of the case examined, namely, the rigid arch with the ends kept from spreading.

It is only necessary to investigate the case of the weight acting eccentrically, since by making the eccentricity = zero, or the acting weight = zero, this may be made to include the cases of the weight acting on the centre of the crown, or that of the heavy rib acted on by no additional weight.

Let the radius C O = R (Fig. G), and A O C, the semi-angle of the rib, $= \alpha$.

Supposing the weight W to act at the point P, let P O C $= \beta$, and let the weight of unity of length of the arch rib $= \omega$, and let H and K be the horizontal and vertical forces acting at A, H being the horizontal thrust.

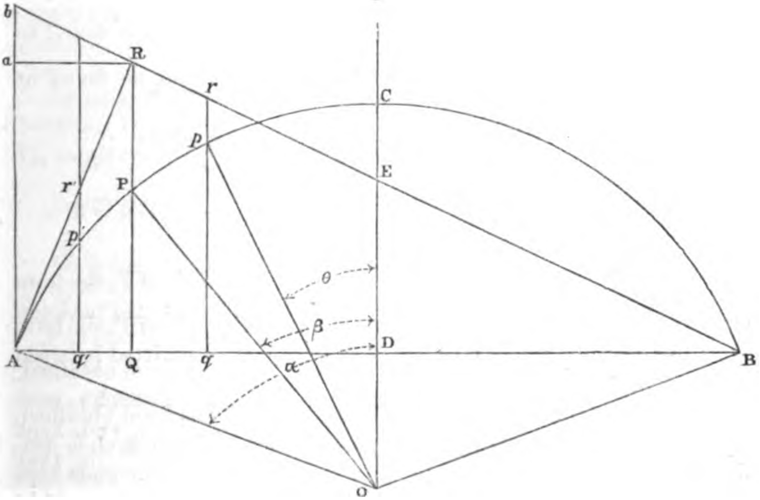
For any point p to the right of P, for which the angle C O $p = \theta$, the moment M of all the forces acting at p will be—

M = weight of arc p A $\times$ horizontal distance of its centre of gravity from $p +$ W $\times$ Q$q +$ H $\times$ $p\,q$ $-$ K $\times$ Aq.

If p be to the left of P, the term W $\times$ Qq in this value of M must be omitted.

To find the first term, θ being considered as a variable angle, the weight of an elementary portion of the arc $R\,d\,\theta$ is $\omega\,R\,d\,\theta$, the horizontal distance of its centre of gravity from C is $R \sin \theta$, and the moment with respect to C is $\omega\,R^2 \sin \theta\,d\,\theta$, the integral of which, for the arc C p between $\theta = 0$ and $\theta = \theta$, is $\omega\,R^2\,(1 - \cos \theta)$.

Fig. G.



In like manner, the moment of the arc C A with respect to C is $\omega\,R^2\,(1 - \cos \alpha)$, and the moment of p A, or the difference of these two, is $\omega\,R^2\,(\cos \theta - \cos \alpha)$.

The horizontal distance of the centre of gravity of p A from C is therefore, $\omega\,R\,(\alpha - \theta)$ being the weight of p A,

$$\frac{\omega\,R^2\,(\cos \theta - \cos \alpha)}{\omega\,R\,(\alpha - \theta)} \quad \text{or} \quad R \cdot \frac{\cos \theta - \cos \alpha}{\alpha - \theta}$$

and its horizontal distance from p is

$$R \cdot \frac{\cos\theta - \cos a}{a - \theta} - R \sin\theta,$$

and the moment with respect to p,

$$\omega R (a - \theta) \left\{ R \frac{\cos\theta - \cos a}{a - \theta} - R \sin\theta \right\},$$

or, $$\omega R^2 (\cos\theta - \cos a + \theta \sin\theta - a \sin\theta).$$

Also
$$\begin{aligned} Q\,q &= R(\sin\beta - \sin\theta) \\ p\,q &= R(\cos\theta - \cos a) \\ A\,q &= R(\sin a - \sin\theta). \end{aligned}$$

To find the upward pressure K, take moments with respect to B:

$$K \times AB = W \times QB + \text{weight of } ACB \times DB,$$

or, $$K R (2 \sin a) = W R (\sin a + \sin\beta) + \omega R \, 2 a R \sin a$$

$$K = \frac{W}{2} \cdot \frac{\sin a + \sin\beta}{\sin a} + \omega R a,$$

and the above value of M becomes, after reduction, as found by Mr. Airy,

$$\begin{aligned} M = {} & \omega R^2 (\cos\theta + \theta \sin\theta - \cos a - a \sin a) \\ & + W R (\sin\beta - \sin\theta) \\ & + H R (\cos\theta - \cos a) \quad \ldots\ldots \quad (7) \\ & + \frac{W}{2} R \cdot \frac{\sin a + \sin\beta}{\sin a} (\sin\theta - \sin a), \end{aligned}$$

where it is to be observed that for a point to the left of P, the term $W \times Q\,q$, or the term $W R (\sin\beta - \sin\theta)$, must be omitted between $\theta = +\beta$ and $\theta = +a$.

From the manner in which this value of M has been obtained, it will evidently have the same expression, whether the arch is considered as a voussoir arch, or as a rigid arch with the ends kept from spreading, the difference between these two cases being that the value of H is different for each.

For the rigid arch with the ends fixed, there will be a bending moment μ, for the present unknown, acting at A, and over the whole arch rib, until it is met and counteracted by the equal but opposite moment $-\mu$ acting at the point B. In this case, therefore, the bending moment at any point will be $M + \mu$ instead of M.

The unknown horizontal thrust H, which appears in the value of M, will now be determined.

For the voussoir arch, there being no bending moment or transverse stress at the crown, taking moments to the left of C with respect to that point:

Moment of arc C A + W × Q D + H × D C = K × A D,

or,
$$\omega R^2 (1 - \cos\alpha) + W \times R \sin\beta + H R (1 - \cos\alpha)$$
$$= \left\{ \frac{W}{2} \frac{\sin\alpha + \sin\beta}{\sin\alpha} + \omega R \alpha \right\} R \sin\alpha,$$

and reducing,

$$H = \frac{W}{2} \cdot \frac{\sin\alpha - \sin\beta}{1 - \cos\alpha} + \omega R \left(\frac{\alpha \sin\alpha}{1 - \cos\alpha} - 1 \right) \qquad (8)$$

In the case of the rigid arch with the ends kept from spreading, the condition of equation (6) must be satisfied, or

$$\Sigma (M \times P Q) = 0$$

and since
$$\Delta s = R \Delta \theta$$
$$\int_{-\alpha}^{+\alpha} M \cdot R (\cos\theta - \cos\alpha) R \, d\theta = 0.$$

Bearing in mind the omission of the term W R $(\sin\beta - \sin\theta)$ between $+\beta$ and $+\alpha$ in the integration, the resulting value of H, as given in Mr. Airy's treatise, is

$$H = \omega R \frac{\alpha^2 \sin\alpha \cos\alpha + \alpha (\frac{9}{4} \cos^2\alpha - \frac{1}{4} \sin^2\alpha) - \frac{9}{4} \sin\alpha \cos\alpha}{\frac{3}{2} \sin\alpha \cos\alpha - \alpha (\frac{1}{2} \sin^2\alpha + \frac{3}{2} \cos^2\alpha)} \qquad (9)$$
$$+ \frac{W}{2} \cdot \frac{\frac{3}{2} \cos^2\alpha - \frac{1}{2} \cos^2\beta - \cos\alpha \cos\beta + (\alpha \sin\alpha - \beta \sin\beta) \cos\alpha}{\frac{3}{2} \sin\alpha \cos\alpha - \alpha (\frac{1}{2} \sin^2\alpha + \frac{3}{2} \cos^2\alpha)}.$$

For the rigid arch with the ends fixed, both in direction and position, $M + \mu$ must be substituted for M in the above integration, which changes it to

$$\int_{-\alpha}^{+\alpha} M (\cos\theta - \cos\alpha) \, d\theta + \int^{+\alpha} \mu (\cos\theta - \cos\alpha) \, d\theta = 0,$$

Integrating,

$$0 = \omega R^2 \left\{ \begin{array}{c} - \frac{9}{2} \sin\alpha \cos\alpha + \alpha (\frac{9}{2} \cos^2\alpha - \frac{1}{2} \sin^2\alpha) \\ + \alpha^2 \cdot 2 \sin\alpha \cos\alpha \end{array} \right\}$$
$$+ W R \left\{ \begin{array}{c} \frac{3}{2} \cos^2\alpha - \frac{1}{2} \cos^2\beta - \cos\alpha \cos\beta \\ + (\alpha \sin\alpha - \beta \sin\beta) \cos\alpha \end{array} \right\} \qquad (10)$$
$$+ H R \{ \alpha (\sin^2\alpha + 3 \cos^2\alpha) - 3 \sin\alpha \cos\alpha \}$$
$$+ \mu \cdot 2 (\sin\alpha - \alpha \cos\alpha).$$

In this case the condition of equation (3) is also to be satisfied,

or, $$\int_{-\alpha}^{+\alpha} M R \, d\theta = O.$$

Substituting in this the value of M from equation (7), integrating between the limits $-\alpha$ and $+\alpha$, omitting the term W R $(\sin\beta - \sin\theta)$ between $+\beta$ and $+\alpha$, and reducing,

$$\begin{aligned} O = {} & \omega R^2 \left\{ 2\left(\frac{\sin\alpha}{\alpha} - \cos\alpha\right) - \alpha\sin\alpha \right\} \\ & + \frac{W}{2} R \left\{ \frac{\cos\beta}{\alpha} - \frac{\cos\alpha}{\alpha} + \frac{\beta}{\alpha}\sin\beta - \sin\alpha \right\} \qquad (11) \\ & + H R \left\{ \frac{\sin\alpha}{\alpha} - \cos\alpha \right\} \\ & + \mu. \end{aligned}$$

From (8) and (9) the values of H being determined and substituted in (7), the bending moment M at any point of the voussoir and rigid arch with the ends kept from spreading may be found; and in like manner from (10) and (11) the values of H and μ may be determined, and the resulting value of $M + \mu$ from (7), will give the bending moment at any point of the rigid arch with the ends fixed.

For $\alpha = 60^\circ$ $\beta = 0^\circ$.

Equation (8) becomes

$$H = \cdot 866\, W + \cdot 814\, \omega R,$$

and equation (9),

$$H = \cdot 631\, W + \cdot 787\, \omega R;$$

also equations (10) and (11) become

$$O = -\cdot 172\, W R - \cdot 213\, \omega R^2 + \cdot 272\, H R + \cdot 685\, \mu$$

$$O = -\cdot 195\, W R - \cdot 253\, \omega R^2 + \cdot 327\, H R + \mu,$$

giving

$$H = \cdot 805\, W + \cdot 841\, \omega R$$

$$\mu = -\cdot 022\, \omega R^2 - \cdot 069\, W R.$$

In like manner, for $\alpha = 60^\circ$, $\beta = 30^\circ$, equation (8) becomes

$$H = \cdot 366\, W + \cdot 814\, \omega R,$$

and equation (9),

$$H = \cdot 406\, W + \cdot 787\, \omega R;$$

Equations (10) and (11) become

$$O = -\cdot110\,W\,R - \cdot213\,\omega\,R^2 + \cdot272\,H\,R + \cdot685\,\mu$$
$$O = -\cdot133\,W\,R - \cdot253\,\omega\,R^2 + \cdot327\,H\,R + \mu,$$

giving

$$H = \cdot401\,W + \cdot841\,\omega\,R$$
$$\mu = -\cdot022\,\omega\,R^2 + \cdot002\,W\,R.$$

To compare the bending moments with those derived from Figs. 2, 3, and 4, since

$$M = H \times P\,N \quad \text{(Fig. F)}$$
$$P\,N = \frac{M}{H},$$

or, in the case of the arch with the ends fixed in direction,

$$P\,N = \frac{M + \mu}{H}.$$

Now, if the values of P N be calculated from these equations, it will be found that they can, for all practical purposes, be equally well ascertained by scaling their equivalents P N from Figs. 2, 3, and 4 (Plate 3).

Before parting with the above formulæ, an examination of them shows that the expressions for H and M, or $M + \mu$, are the algebraical sums of two parts, one corresponding to $\omega = O$, and the other to $W = O$.

It follows from this, that if at any point the stress, which is proportional to the bending moment, caused by the weight of the rib itself, or rib and its fixed loading, be found, and also that caused by a moving load acting on the point, the total stress is obtained by adding these two stresses together with their proper signs.

As the action of a moving load can thus be separated from the action of a fixed load, it may be useful to examine the cases of a circular rib of 120°, and of a semi-circular arch rib.

Action of the Weight of the Arch.

Figs. 2 and 5 (Plate 3) show the stresses arising from the weight of the arch itself considered as the fixed load. The vertex and springing points were determined by the above formulæ, and the curves of equilibrium drawn to pass through these points. Calling P the weight of the semi-arch, and R its radius, the values of H,

$\frac{M}{H}$ when $\theta = 0$, and of $\frac{\mu}{H}$ are given in the following table:

	For $\alpha = 60°$	For $\alpha = 90°$
Voussoir arch . . .	$H = \cdot 777\ P$	$H = \cdot 363\ P$
Rigid arch—ends kept from spreading . .	$H = \cdot 751\ P$	$H = \cdot 318\ P$
	$\frac{M_{\theta = 0}}{H} = -\cdot 018\ R$	$\frac{M_{\theta = 0}}{H} = -\cdot 142\ R$
Rigid arch with the ends fixed . . .	$H = \cdot 803\ P$	$H = \cdot 407\ P$
	$\frac{M_{\theta = 0}}{H} = -\cdot 009\ R$	$\frac{M_{\theta = 0}}{H} = -\cdot 171\ R$
	$\frac{\mu}{H} = -\cdot 026\ R$	$\frac{\mu}{H} = -\cdot 064\ R$

By these values of $\frac{M}{H}$ when $\theta = 0$, and of $\frac{\mu}{H}$, the vertices and springing points of the curves were determined. It will be observed that the stresses on the rigid arch are in both cases reduced to about one-half by fixing the ends.

The curves of equilibrium for a moving load will now be considered.

Action of a Moving Load.

If the load on a particular point of the arch be the only force acting, since there are then no forces to bend the curve of equilibrium, it becomes two straight lines, meeting in an apex vertically above the load. For the voussoir arch and rigid arch of invariable span, these lines pass through the centres of the ends of the arch rib.

That the bending moments are measured by the vertical ordinates between these lines of equilibrium and the curve of the rib may be shown as follows:

Putting $\omega = 0$ in equation (7), the value of $\frac{M}{H}$ after reduction is

$$\frac{M}{H} = R\left\{\cos\theta - \cos\alpha - \tfrac{1}{2}\frac{W}{H}\cdot\frac{\sin\alpha + \sin\theta}{\sin\alpha}(\sin\alpha - \sin\beta)\right\} \quad (12)$$

If P (Fig. G) be the position of the weight, draw the vertical lines Q P R and A *b* through P and A, and the horizontal line R *a* through R, an assumed apex or intersection of the lines of equilibrium R A, R B.

Then $$W : H :: A b : a R.$$

But $$a R = Q A = R(\sin\alpha - \sin\beta).$$

Therefore $$A b = R\frac{W}{H}(\sin\alpha - \sin\beta).$$

Also $$B D : E D :: B Q : Q R,$$

or, $$Q R = E D \cdot \frac{B Q}{B D} = E D \cdot \frac{R(\sin\alpha + \sin\beta)}{R \sin\alpha}$$

$$= \frac{R}{2}\frac{W}{H}(\sin\alpha - \sin\beta)\frac{\sin\alpha + \sin\beta}{\sin\alpha},$$

and $$P R = Q R - Q P$$

$$= \frac{R}{2}\frac{W}{H} \cdot \frac{\sin\alpha + \sin\beta}{\sin\alpha}(\sin\alpha - \sin\beta) - R(\cos\beta - \cos\alpha);$$

the same as the above value of $\frac{M}{H}$ when $\theta = \beta$, but with an opposite sign, since M has been treated as negative when R is above P.

Then if p be a point to the right of P, for which the angle $p O C = \theta$,

$$B Q : B q :: Q R : q r,$$

and

$$q r = Q R\frac{B q}{B Q} = \tfrac{1}{2}\frac{W}{H}R\frac{\sin\alpha + \sin\beta}{\sin\alpha}(\sin\alpha - \sin\beta)\frac{\sin\alpha + \sin\theta}{\sin\alpha + \sin\beta}$$

$$= \tfrac{1}{2}\frac{W}{H} \cdot R\frac{\sin\alpha + \sin\theta}{\sin\alpha}(\sin\alpha - \sin\beta),$$

and $$p r = q r - q p$$

$$= \tfrac{1}{2}\frac{W}{H}R \cdot \frac{\sin\alpha + \sin\theta}{\sin\alpha}(\sin\alpha - \sin\beta) - R(\cos\theta - \cos\alpha);$$

the same as the general value of $\frac{M}{H}$ in (12), but with a negative sign, as already explained.

For a point to the left of P, the term $W R(\sin\beta - \sin\theta)$ being omitted in the value of M, equation (7) gives

$$\frac{M}{H} = R(\cos\theta - \cos\alpha) + \tfrac{1}{2}\frac{W}{H}R\frac{\sin\alpha + \sin\beta}{\sin\alpha}(\sin\theta - \sin\alpha),$$

and from Fig. G,

$$A Q : A q' :: Q R : q' r'$$

$$q' r' = Q R\frac{A q'}{A Q} = Q R \cdot \frac{\sin\alpha - \sin\theta}{\sin\alpha - \sin\beta}$$

$$= \tfrac{1}{2}\frac{W}{H}R \cdot \frac{\sin\alpha + \sin\beta}{\sin\alpha}(\sin\alpha - \sin\theta),$$

and $$p'r' = q'r' - q'p'$$

$$= \frac{1}{2}\frac{W}{H}R \cdot \frac{\sin\alpha + \sin\beta}{\sin\alpha}(\sin\alpha - \sin\theta) - R(\cos\theta - \cos\alpha),$$

the same as the above value of $\frac{M}{H}$, but with the negative sign.

For the voussoir arch, since there is no bending moment at the crown, one of the lines of equilibrium is fixed by the condition that it must pass through the crown, and through the end of the arch farthest from the load; the other line is fixed by making it pass through the end of the arch nearest the load, and the point where a vertical line through the load cuts the first-mentioned line.

For the rigid arch, a curve line above the arch can be found, such that, for any given position of the load, the vertical line through the load will intersect this curve in a point, which point will be the apex of the two lines of equilibrium for that position of the load.

To draw this curve, or locus of the apex, it is only necessary to find from (12) the value of $\frac{M}{H}$ when $\theta = \beta$, and lay off above the point where the weight acts a vertical length equal to this. By finding a sufficient number of points the curve can be drawn.

Figs. 7 to 10 (Plate 3) show the lines of equilibrium, and the locus of the apex for the arc of 120°, and for the semicircular arc. For the latter, the locus becomes a straight line, drawn at a distance of $\frac{\pi}{2}$ R above the centre of the circle, or its height above this centre is equal to the length of the quadrant.

On Figs. 8 and 11, for the rigid arch with the ends fixed, the lines of equilibrium are shown for different positions of the load, the springing points of these lines being determined by the values of $\frac{\mu}{H}\cdot$ from (10) and (11).

Where so many lines were to be found, it was easier to fix their points of intersection by formulæ already obtained than to find each by a separate graphic construction. The lines are in the same positions as would have been found by construction, the lines of equilibrium on Figs. 7 and 10 satisfying Eq. (6), and those on Figs. 8 and 11, Equations (3) and (6).

But the lines on these Figs. only serve to compare among themselves the stresses on different points of the rib for the same position of the load. The bending moment being compounded of the horizontal thrust, as well as the height P N (Fig. F), it is necessary, in order to compare the absolute stresses for different positions of the load, to take into account the change of horizontal thrust. This comparison may be made by arranging that all the stresses may contain a common factor, and the simplest common factor is the weight itself. The bending moment, or H × P N, may then be assumed equal to W × x, giving,

$$x = \frac{H}{W} \cdot P\,N.$$

That is, by plotting at the different points of the rib, heights or depths less than P N in the ratio of H to W, these new heights being multiplied by W, will give the bending moments.

In this manner, the network of lines on Fig. 6 has been drawn, and the dotted lines, which are passed through the points of maximum bending moment, show the greatest stresses to which the rib is exposed during the passage of a load from one side to the other of the arch rib. It will be observed that the greatest stress occurs when the load is about midway between the crown of the arch and the abutment.

On Figs. 7 to 11, only the dotted lines of maximum bending moment have been drawn. This maximum bending moment is equal to the weight multiplied by the vertical distance between the neutral line of the arch rib, and the dotted line, to the same scale as the arch rib is drawn. For example, in a semicircular rigid arch, of 100 feet span, with the ends kept from spreading, the greatest bending moment for a weight of 10 tons passing along it occurs when the weight is over the centre of the rib, and is measured by 10 tons × 9 feet tending to lessen the curvature; and during the passage of the load there is at a point 50° from the crown a bending moment of 10 tons × 5 feet 3 inches tending to increase the curvature.

Putting k for the length of the line P N (Fig. F),

$$M = H\,k,$$

and denoting by M′, H′, and k', similar quantities corresponding to a weight W′, in like manner,

$$M' = H'\,k'$$

and

$$M + M' = H\,k + H'\,k'.$$

But the horizontal thrust for W and W′ acting together will be H + H′. Let, therefore,

$$(H + H')\,k'' = H\,k + H'\,k'.$$

Then

$$k'' = k \cdot \frac{H}{H + H'} + k' \cdot \frac{H'}{H + H'} \quad . \quad . \quad . \quad (13)$$

or the length P N for the combined curve may be found by adding together the lengths for W and W′, each reduced in the ratio of its horizontal thrust to the total horizontal thrust. An example of this is given in the voussoir arch first examined.

Action of a uniformly distributed Load.

Since the values of H and M are proportional to W, the stress caused by any number of weights is the sum of the stresses caused by each separately, and Figs. 6 to 11 give the means of ascertaining the position and amount of greatest stress for a uniform load, supposed to be put on the arch beginning from one end, until the whole is covered.

But the action of a uniform load on a definite part or the whole of an arch can be arrived at with greater facility by the constructive method of drawing the curves of equilibrium. Examples of this for the rigid arch, with the ends kept from spreading, are given on Figs. 12, 13 and 14, Plate 3. Fig. 12 represents an arch whose rise is $\frac{1}{10}$th of the span. One of the dotted lines (*b*) shows the curve of equilibrium when a moving load, equal per foot run to $\frac{1}{2}$ the fixed load, has a uniform horizontal distribution over one-half of the arch in its central part; and the other dotted line (*c*) shows the curve when the uniform horizontal distribution of the moving load is over the half of the arch from the centre to the abutment.

Fig. 13 represents the arch of 120° already examined. The dotted line (*a*) is the curve, a parabola, for the rigid arch with the span invariable, under a uniform horizontal loading all over. The dotted line (*b*) shows the curve when a moving load, equal to $\frac{1}{2}$ the fixed load per foot run, extends over $\frac{1}{4}$ of the span each way from the centre, or over $\frac{1}{2}$ the span altogether, the dotted line (*c*), when the same moving load extends from the centre to one of the abutments.

For the sake of comparison with the last, Fig. 14 shows the curves of the rigid arch of invariable span, the form of the arch being not circular but parabolic. The parabola is the curve of equilibrium for a uniform horizontal load, so that when the loading is distributed all over the span, the curve of equilibrium coincides with the curve of the arch rib, and there is no transverse stress. The dotted line (*b*) shows the curve with the above-mentioned moving load extending over $\frac{1}{4}$th of the span each way from the centre; the dotted line (*c*) shows the curve when the moving load extends from the centre to one of the abutments.

The loading being supposed uniform horizontally, the weight which acts at each of the verticals is proportional to the horizontal projection of the division of the arc which it bisects. From these weights the curves of equilibrium have been constructed so as to satisfy equation (6).

It will be observed that when the moving load extends from the centre to the abutment, although the transverse stress tending to diminish the curvature of the arch at its loaded part is considerable, there is an equal, and in the case of the arc of 120° a rather greater, transverse stress at the unloaded haunch tending to increase the curvature. Since the inequality of the loading may act on the opposite side of the arch, the curves may be transferred from one side to the other, and the stresses reversed. When the moving load acts on $\frac{1}{4}$ of the span each way from the centre, the transverse stress tending to increase the curvature at the haunches is rather greater than the stress of the opposite kind at the centre of the arch.

The curves for the parabolic rib show rather less stresses for partial loading than those for the circular rib, so that the former, which has no transverse stress when the load is uniformly distributed over it horizontally, has a slight advantage over the circular rib in the event of unequal loading. As the rise of the arch is diminished, the circular and parabolic curves come so close together as to be practically the same.

Straight or Curved Girder.

Putting m for the bending moment of all the vertical forces, the value of M in Eq. (7)—Fig. G—may be written

$$M = m + H \cdot PQ.$$

This quantity m, or the sum of all those terms which do not contain H, is nothing else than the bending moment, supposing the arch were a girder.

If the arch becomes a girder,

and $M = m$,

then $H = 0$;

and, as already remarked, the ordinates of the curve of equilibrium are infinite.

But (Fig. F) bearing in mind that M is negative at the point P,

$$M = -H \cdot PN = m + H \cdot PQ,$$

and $$-m = H(PQ + PN) = H \cdot NQ.$$

That is, H · N Q is the graphic representation of the bending moment of a girder of the same shape and loading as the arch. Since N Q is the vertical distance between the curve of equilibrium and the straight line, the bending moment is independent of the shape of the arch, which may be either curved or straight.

A straight or curved girder then may be considered as an arch of any rise, but without horizontal thrust; and if its length be divided into parts, and any curve of equilibrium drawn for the weights, continuous or discontinuous, acting on these parts, the stress at any point P will be represented by the value of H · N Q. Since H varies inversely as N Q, H · N Q will be the same for all the curves of equilibrium that can be drawn. This remark leads to the following method of ascertaining the stresses on a continuous beam.

Continuous Beam.

While examining, in the year 1849, the stresses on continuous beams for the late Mr. Brunel, in reference to the large bridge at Chepstow, the lower girder of which is virtually a continuous beam of five unequal spans, the Author, using the method of Navier, found the subject one of no inconsiderable difficulty, from the number and complexity of the eliminations required; and he was gratified by the formulæ at which he then arrived, for beams up to five spans, being completely verified by the experimental tests to which he subjected them, and which were devised by Mr. Brunel. One of these experiments is described in Mr. Edwin Clark's work on the Britannia Bridge.[1]

Since that time, the discovery of the "theorem of three moments"[2] has introduced great simplicity in the consideration of continuous beams of uniform section; and recently Mr. Heppel, in a Paper read before the Royal Society of London,[3] has been the first to solve the general problem of the continuous beam of varying section, and of any number of spans or manner of loading. The solution depends on certain definite integrals, which if they cannot always be obtained in a finite form, may, by the method of quadratures, be approximated to with as great numerical accuracy as may be desired.

Aware of the difficulty of the subject, the Author ventures to present it under a somewhat different aspect, and hopes to show, in the following remarks, that the stresses on a continuous beam of varying or uniform section may be ascertained with sufficient accuracy for practical purposes by a modification of the method of finding the stresses on rigid arches.

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[1] *Vide* Britannia and Conway Tubular Bridges, vol. i., p. 462.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxix., pp. 44–48.

[3] *Vide* Proceedings of the Royal Society of London, vol. xix., p. 56.

It will be convenient in the first instance to consider beams of uniform section.

For these, though loaded in any manner whatever, if they are supposed disconnected at the piers, a curve of equilibrium for each span may be drawn, the rise of the curve being arbitrary. And all the forces being vertical, the bending moment or stress at any point (see p. 38) would be measured by the horizontal thrust, multiplied by the vertical ordinate.

The condition that the sum of the upward pressures at the points of support must be equal to the downward pressures of the weights, would be complied with, since the weight acting on each span would be borne by the end supports.

When the beams are supposed to be connected together, so as to form one continuous beam extending over the whole of the spans, the above condition must still be satisfied; but, in consequence of the continuity, the weights borne by the different points of support will not be the same as when the beams are unconnected, and the differences will introduce bending moments at the points of support, and at every point of the beam, except at the two ends, where the bending moments are zero, unless external forces act on the beam at these points.

On the diagrams of the curves of equilibrium, the bending moments at the piers may be represented by vertical straight lines, each being the bending moment divided by the horizontal thrust.

On Fig. H, Plate 3A, A C B and B E D being curves of equilibrium, for the weights acting on the spans A B, and B D, B x and D y represent the bending moments at B and D, and the stress at any point t, due to the alteration of pressure at the points of support caused by the continuity, will be represented by a vertical ordinate $t\,s$, from the straight line A B D to the straight lines A x, $x\,y$; and the actual stresses at any point t of the beam supposed continuous is represented by the difference between the ordinate of the curve and of the straight line, and is therefore equal to the horizontal thrust multiplied by $r\,s$.

And because, for any one pier, the bending moment there must be the same, whether moments are reckoned to the right or left, the horizontal thrust on one side, which requires to be multiplied by the length of the vertical line already mentioned to give the bending moment, must be equal to the horizontal thrust on the other side; that is, the horizontal thrusts of two adjoining curves must be the same; and since the thrust is also constant throughout the same curve, it follows that in order to have a set of curves, the ordinates of which will represent the stresses on a continuous beam, it is necessary that the horizontal thrusts for the different spans should be all equal to one another, or the arches which these curves represent should be balanced arches. One curve being drawn, all the others are determined by this condition.

Commencing at one end A of the beam (Fig. H), draw the curve of equilibrium A C B for the weights acting on the span A B, of any convenient rise C G, measured on the same scale as that for the span A B, and call H the horizontal thrust of this curve.

To draw the curve for the next span, dividing the length B D in the middle, or any other convenient point m, let P P′ and Q Q′ be the vertical lines passing through the centres of gravity of the sums P and Q of the weights which act between m and B and m and D. From the positions of these weights, the vertical reactions at B and D may be found, the beam being at present not supposed to be continuous. Making B a equal to H, and a b equal to the upward reaction at B, the line B b will be tangential to the curve of equilibrium at the point B, and will cut the vertical line P P′ in the point P′. Similarly, the tangent at D may be found, and this will cut the vertical line Q Q′ in the point Q′. Joining P′ and Q′, the line P′ Q′ will be tangential to the curve of equilibrium at the point E in the vertical line E m, and the rise of the curve B E D will thus be determined. The curve for the span B D may then be drawn, and so on for the other spans.

Having thus drawn, on the horizontal line passing through the points of support, a series of curves of uniform horizontal thrust for the different spans, divide the whole length of the beam into any convenient number of equal parts, and draw vertical lines $t_0\, r_0$, $t_1\, r_1$, &c., through the centres of these divisions. If B x, D y, &c., be drawn tentatively to represent the bending moments at B, D, &c., caused by the altered pressures on the piers, the ordinates $s_0\, r_0$, $s_1\, r_1$, &c., will represent tentatively the stresses on the beam. And if a curve A K_0 B_1 K_1 D_1 F_1, &c., be drawn in such manner that at any point t the ordinate $t\, u$ is the algebraical sum, to any convenient scale, of all the ordinates $r_0\, s_0$, $r_1\, s_1$, &c., from A up to t, $t\, u$ will represent the area A C r s, or the change of angle of the elastic curve of the beam between A and t. Drawing, then, through this curve, and for the first span, a line $A_0\, B_0$, parallel to A B, so as to make the area A A_0 K_0 equal to the area $B_1 B_0 K_0$, the line $A A_0$ will represent the constant to be added in the integration to make these areas equal, or the ordinate of the elastic curve equal to zero at the point B; since this ordinate is represented by the sums of the ordinates or the area of this derived curve. By the addition of the constant, the axis is shifted from A B to $A_0 B_0$; and since the slope of the beam at the point B for the part A B must be the same as for the part B D, the curve $B_1 K_1 D_1$ for the second span must have the same ordinate $B_0 B_1$ at B as that of the curve of the first span. That is, the axis of the curve for the second span lies in the prolongation of the axis for the first span. The same condition of equality of areas subsists, or the area $B_1 B_0 K_1$ must be equal to the area $D_0 D_1 K_1$. Similar remarks apply to the remaining spans.

In order, therefore, to ascertain the stresses on a continuous beam of uniform section, the primary curves of equilibrium must have the same horizontal thrust, and the derived curve $A K_0 B_1 K_1$, &c., must be capable of being cut by a line parallel to A B, in such manner, that the areas above and below this line, for each span, shall balance one another. The heights B x, D y, are to be arranged so that this condition is satisfied.

Fig. H, Plate 3A, is an example of the solution of the case of a continuous beam of three unequal spans, the conditions of each of which are purposely made as dissimilar to those of the others as possible. The lengths A B, B D, and D F, have been assumed in the proportions of 4, 2, and 1; A B has been supposed loaded with a weight of 4, B D with a weight of 1, distributed over the span uniformly, and D F has been supposed unloaded.

The Author's diagrams of the curves of bending moment (Plate 12A, p. 190, vol. xxxii., Minutes of Proceedings Inst. C.E.) may be referred to as showing the lengths of the lines B x, D y, &c., under different conditions. These curves were constructed from the algebraical equations, but they are also true curves of equilibrium, with the springing points at different levels, for the insistent weights on the different spans. Curves corresponding to these for Fig. H are indicated by the dotted lines A C′ x' E′ y'. These curves may be derived from A C B E D by making B x' = B x, D y' = D y, and erecting on the sloping lines A x', x' y', vertical ordinates equal to the ordinates of the curves A C B E D measured from the horizontal line A B D. That is, for any point t, the line $r\,t$ being produced, to cut A x' in t', the vertical height $t'\,r'$ is made equal to $t\,r$. The bending moment at any point is thus equally represented by the line $r\,s$ of the curve

A C B E D, or by the line $r' t$ of the curve A C′ x' E′ y'. The reason for constructing the curves of equilibrium on the horizontal lines A B, B D, &c., instead of on the sloping lines A x', &c., is, that the sums of the ordinates, or areas of the curve of moments, can then readily be found for any positions of the points x, y, &c.; while if these areas had to be obtained from curves drawn on the sloping lines, new curves of equilibrium would be required for each different position of the points x, y, &c.

The lengths B x, D y, &c., may be approximated to by assuming the beam to be severed at the ends of the several spans, beginning with the second. For the beam supposed continuous over the first two spans only, D y = zero, and the length B x can be readily found by balancing the areas of the derived curve A m n D_2, as already explained. If the beam be then supposed continuous over the first three spans, B x and D y may be determined after one or two trials by balancing the areas, and it will generally be found that B x will only differ slightly from the value already found for the continuous beam of two spans. Another span having been added, or the beam being supposed continuous over four spans, B x will scarcely require alteration, while D y will only require to be altered slightly. This process may be continued for any number of spans, and for any manner of loading. An examination of the curves on the Plate 12A already referred to shows, that the effect of loading any span is scarcely felt beyond the third or fourth span from the one loaded. In Fig. H, the dotted line A m n D_2 is the derived curve for the beam supposed continuous over the first two spans only, and B x_2 is the corresponding bending moment at B, which in this case requires to be altered by the quantity $x\,x_2$ to suit the assumption of continuity over three spans instead of two.

The appropriate lines A x, $x\,y$, &c., having been determined, the points of contrary flexure and of greatest bending moment can be ascertained by inspection of the diagram.

The slope and ordinate of the elastic curve of the beam at any point may also be found as follows:

Calling λ the vertical ordinate $r\,s$ between the curve of equilibrium and the lines A x, x, y, &c., measured by the same scale as the spans A B, B D, &c.; the bending moment M is equivalent to H λ, and the equation of equilibrium is

$$\mathrm{E\,I}\frac{\Delta^2 y}{\Delta x^2} = \mathrm{H}\,\lambda\,;$$

x being put for the abscissa A, t, and y for the ordinate of the elastic curve of the beam, $+x$ measured from A towards B, and $+y$ measured downwards.

Hence,
$$E\,I\cdot\frac{\Delta y}{\Delta x} = H\left\{\Sigma\,(\lambda\cdot\Delta x) + C\right\}$$
$$= H\cdot\Delta x\left(\Sigma\,(\lambda) + \frac{C}{\Delta x}\right)$$

But by the construction $\Sigma\,(\lambda)$ is represented by the ordinate *t u* of the curve A K_0 B_1, &c., and A A_0 represents the arbitrary constant or $\frac{C}{\Delta x}$, in this case negative; *v u* is therefore equal to $\Sigma\,(\lambda) + \frac{C}{\Delta x}$, and if *v u* be put equal to ν
$$\frac{\Delta y}{\Delta x} = \frac{H\cdot\Delta x}{E\cdot I}\cdot\nu,$$
an equation which gives the slope of the elastic curve of the beam at any point.

And for the ordinate of the elastic curve
$$y = \frac{H\,(\Delta x)^2}{E\cdot I}\,\Sigma\,(\nu);$$
it being assumed that $y = 0$ when $x = 0$, or that the summation is commenced from the point A.

In reference to the above process it should be remarked that by making *t u* equal, on the appropriate scale, to the sum of all the ordinates *r s*, from A up to and inclusive of *r s*, *t u* thus really represents the sum of the heights of elementary parallelograms, or area A C *r s* divided by Δx, not up to *r s*, but up to a vertical line half-way between *r s* and the next line of division further from A.

If the number of parts into which A B, &c., is divided be considerable, the inaccuracy is slight: in order to be quite accurate, the ordinate *t u* should be plotted half a division further from A than the ordinate *r s*, and *t u* will then represent the area of the curve A C *r s* up to a point of the beam, corresponding to the point *u* of the curve A K_0 B_1, &c. A similar remark applies to the ordinates *v u* of the curve A K_0 B_1, the sum of which represents, on the appropriate scale, the ordinate of the elastic curve; this sum up to any point *t* should be equal to the area contained between the straight line A_0 B_0 D_0, &c., and the curve A K_0 B_1 from A up to the point *t*. A correction like that above described may be applied here, but as small errors are cumulative in integrating twice, it will be more accurate to measure by scale the ordinates of the curve A K_0 B_1, &c., and enter these measurements in the summation which expresses the ordinates of the elastic curve.

For any of the spans acted on only by a definite load at a given point, the curve of equilibrium is two straight lines as explained (p. 86), the horizontal thrust being the same as for the other spans.

If some of the spans are unloaded, as the span D F, Fig. H, the curve of equilibrium for one of these spans is a straight line D F joining the points of support; this line may be considered as representing a strut without weight, which conveys the horizontal thrust across the span, and vertical lines upwards or downwards, as may be necessary, will require to be drawn as before, in order to construct the derived curve and balance the areas.

If one or more of the points of support is not at the same level, and the continuous beam originally straight, the balancing of the areas will require to be arranged so that at the point corresponding to the support which is out of level a small overplus may be left equal to the appropriate area which will represent the amount of difference of level. If y in the above formula be put equal to this difference of level, $(\Delta x)^2 \Sigma (\nu)$ will be the overplus of area.

To adapt the method to a continuous beam of varying section, it is only necessary in constructing the derived curve A K_0 B_1, &c., to substitute $\frac{r_0 s_0}{I_0}$, $\frac{r_1 s_1}{I_1}$, &c., in the summations, instead of $r_0 s_0$, $r_1 s_1$, &c.; I_0 I_1, &c., being the values of I for the cross section of the beam at the different points. B x, D y, &c., having been arranged so that the areas balance with these substitutions for $r_0 s_0$, $r_1 s_1$, the bending moments will be equal to the horizontal thrust multiplied by the ordinates $r_0 s_0$, $r_1 s_1$, &c.

If the section of the beam varies in such a manner that I is everywhere proportioned to the strain, the values of $\frac{r_0 s_0}{I_0}$, $\frac{r_1 s_1}{I_1}$, &c., are constant, and the derived curve is a series of straight lines; the areas to be balanced are triangular, and if the proportion, or the constant $\frac{r s}{I}$, is the same for each piece of the beam lying between the points of contrary flexure, all the straight lines will cut the axis A_0 F_0 at the same angle, and the approximation may be made with much greater facility than if the section of the beam were uniform.

On Fig. H, the straight lines A T, T U, U F′, have been drawn so that the angles T e B_0, T g B_0, and U k D_0 are equal to one another; and the areas A A_0 e, f B_0 g, and h D_0 k are respectively equal to the areas e T f B_0, g U h D_0, and k F′ F_0. The points of contrary flexure α' and β', where the bending moment is zero, are determined by drawing the lines T α', U β' through T and U parallel to A A_0: these lines will cut the curve of equilibrium in the points ρ' and σ'. Joining the points A and ρ', the line A ρ' produced will cut the line B x in the point x_1, and the points x_1 and σ' being joined, the line x_1 σ' produced will cut the line D y in the point z. B x_1 and D z are the bending moments at B and D on the above supposition. It appears that in the case represented by Fig. H, which is probably an extreme one, the condition that the section varies as the strain, instead of being constant, involves an alteration of the points x and y to x_1 and z. On the whole, the bending moments of the large spans are not materially altered, and the Author observes that Mr. Heppel has made a similar remark. In the first case the stress per square inch on the outer surfaces of the beam would be of the same amount throughout; in the second it would vary as the bending moment.

Should it be desired to obtain the pressures on the piers, this may be done by taking moments for each pier successively, beginning with the end span, and including the moments H × B x, H × D y, &c., as follows:

Let W_1 be the load on the first span, and p the horizontal distance from B of the vertical line passing through the centre of gravity of W_1. In like manner for the second span, let W_2 be the load, and q the horizontal distance from D of the vertical line which passes through the centre of gravity of W_2: and let W_3, W_4, &c., r, s, &c., be corresponding quantities for the succeeding spans. Then calling s_1, s_2, s_3, &c., the lengths of the spans reckoning from A towards the right, and r_0, r_1, r_2, r_3, &c., the upward pressures at the piers beginning from A, r_0 being the upward pressure at A, if moments be taken round the ends of the 1st, 2nd, 3rd, &c., spans successively, the following equations are obtained:

$$W_1\,p + H\,.\,B\,x - r_0\,s_1 = 0$$
$$W_2\,q + W_1\,(p + s_2) + H\,.\,D\,y - r_1\,s_2 - r_0\,(s_1 + s_2) = 0.$$
$$\text{\&c.} \;.\;\;.\;\;.\;\; \text{\&c.} \;.\;\;.\;\;.\;\; = \text{\&c.}$$

From the first of these equations r_0 may be found, and by inserting this value of r_0 in the second equation, r_1 may be found, and so on for r_2, r_3, &c.

In these equations, B x, D y, &c., are to be reckoned as positive if x, y, &c., are below the line A B; the moment of the horizontal thrust then tends to turn the system in the same direction as the weights W_1, W_2, &c. In Fig. H, B x is negative, and D y positive.

If only one span be considered, the method above described affords a simple means of proving all the propositions relating to stress and deflection, for a beam with the ends free, or with one or both ends 'fixed;' and with the load either acting at a given point or uniformly distributed over the span.

The action of oblique forces will now be considered.

OBLIQUE FORCES.

From what has been said as to the effect of transverse stress on the curvature of an arch rib, it will be seen that what determines the change of curvature is the amount of bending moment, and that it is of no consequence whether this has been produced by the action of vertical or oblique forces if the amount be the same. The different conditions already investigated will still subsist under oblique forces, due care being taken to obtain the correct value of M, which can no longer be taken to be represented by the line P N (Fig. F), as in the case of vertical forces.

Curved Dock Gate.

As the condition of dock gates under the pressure of water is in a great degree analogous to that of the voussoir arch, or arch hinged at the centre, the first and most simple illustration of oblique pressures will be that of the curved dock gates of the Victoria Docks, described at vol. xviii., p. 445, of the Minutes of Proceedings of the Institution of Civil Engineers.

Fig. 15 (Plate 3) shows a plan of one leaf of this dock gate, the surface exposed to the pressure of the water being circular. The other surface is also circular, but not concentric with the first, the gate being 3 feet wide at the middle, and only 2 feet at the ends. The neutral line is shown by the centres of the small circles midway between the two surfaces. The span of the lock is 80 feet.

C s_1 s_2 . . . B, being the surface exposed to the pressure of the water, if all the pressures on it be resolved parallel to C D, the resultant may be represented by B D, and will pass through the middle point *d* of B D. Similarly, if the pressures are resolved parallel to B D, the resultant may be represented by the length C D, and will pass through the point *c* in the middle of this length. Draw the lines *d b* and *c e* respectively parallel to C D and D B, and therefore in the directions of these resultants. These lines will intersect one another in some point *a*, and if *a b* be laid off equal to D *d* = $\frac{1}{2}$ D B, and *b f* be drawn parallel to *c e* and equal to C *c* = $\frac{1}{2}$ C D, then *a f* to the same scale will be the amount, and will be in the direction of the resultant of all the pressures along C s_1 s_2 . . . B, and will be normal to this surface.

To construct the curve of equilibrium, which will pass through the heel post A, and some point x in the meeting post, divide the neutral line into a number of equal parts—in the figure there are twenty—and draw the normals $p_1\,s_1$, $p_2\,s_2$, &c., through the middle points of these divisions, cutting the outer surface in s_1, s_2, &c. Then, since the scale used is such that the pressure D B is represented by $a\,b$ or ½ D B, the pressures on $s_1\,s_2$, $s_2\,s_3$, &c., which are all equal, will be represented by ½ $(s_1\,s_2)$, and the normals will be the directions of these forces. Draw $x\,h$ parallel to C D, cutting the line $f\,a$ produced in a', and join A a', which will be the direction of the force passing through A. And if $f'\,a'$ be made equal to $f\,a$, and $f'\,g$ be drawn parallel to $x\,h$ to cut a' A in g, $g\,a'$ will be the amount of the force at A, and $f'\,g$ the force at x.

Draw $g\,h$ parallel to $f\,a$, cutting $x\,h$ in h, and $g\,h$ will be equal to $f\,a$ or $f'\,a'$. Draw $h\,q_1$ parallel to $p_1\,s_1$, and equal to ½ of $s_1\,s_2$, and from the point q_1, so found, draw $q_1\,q_2$ parallel to $p_2\,s_2$, and also equal to ½ of $s_1\,s_2$. Continue this construction of the force diagram for the remaining normals p_3, s_3, &c., and if correct, the last point so found will coincide with g.

The curve of equilibrium is then constructed by drawing from the point r_1, where the first normal $p_1\,s_1$ cuts the line $x\,h$, $r_1\,r_2$ parallel to $a'\,q_1$, to cut $p_2\,s_2$ in r_2. From the point r_2 so found draw $r_2\,r_3$ parallel to $a'\,q_2$ to cut $p_3\,s_3$ in r_3, and continue this construction, which will terminate by the last line drawn passing through the point A, and coinciding with a' A.

In this manner the curves of equilibrium on the figure have been drawn.

The central dotted line shows the curve of equilibrium which passes through the centre of the meeting post, supposing the gates to bear on each other at that point. It will be observed that, except at the ends of this line, there is a slight amount of transverse stress tending to diminish the curvature of the gate. This stress attains a maximum in the centre of the leaf, where the curve of equilibrium is about 4 inches distant from the neutral line. By the remarks on Eq. (6*a*), if the gate be considered as a box girder, and the curve touched the outer surface, the compressive stress would there be approximately double of that due to the uniform compression if the curve of equilibrium were central, and at the opposite side the stress would be zero. But as the curve is only about $\frac{2}{9}$ths of the distance to the outer surface, the compressive stress there will be increased to $1\frac{2}{9}$, and at the opposite side will be diminished to $\frac{7}{9}$ths of the stress due to the uniform compression.

This result depends on the point of contact of the gates, and these stresses might be altered to $1\frac{1}{9}$th and $\frac{8}{9}$ths respectively by dubbing the timber and making the point of contact about 3 inches nearer the centre of the circle than the middle of the meeting post.

In order that there should be no transverse stress, the curve of equilibrium should be midway between the outer and inner surfaces; this could be easily arranged in constructing gates, by making the thickness so as to satisfy this condition.

The other dotted lines show curves of equilibrium passing through points 3 inches distant from the outer and inner surfaces, and are intended to show how the stresses would be altered by an obstruction getting between the gates, and forcing the curve to pass through these points. It will be observed that in that case there would be a gradual increase of transverse stress up to the meeting post.

The curves of equilibrium for a straight gate, or gate of any other form, may evidently be drawn in a similar manner.

Elliptical Caisson.

As an example of transverse stresses on a closed figure, the curve of equilibrium of the elliptical caissons used in the foundations of the Thames Embankment near Westminster Bridge will now be investigated.

These caissons (see "Builder" for 1864, p. 574) were elliptic cylinders, with a major axis of 12 feet 6 inches and a minor axis of 7 feet. They were made of wrought-iron plate about $\frac{3}{8}$ths inch thick, and stiffened by angle irons.

Fig. 16 (Plate 3) represents a section of the caisson, O being the centre and A O, C O the semi-axes.

If all the pressures on the quadrant A B C of the ellipse were resolved in a direction parallel to A O, the resultant would be a single force proportional to C O, and passing through the middle of C O. In like manner, the resultant of the pressures resolved parallel to C O would be a force proportional to A O, and passing through the middle of A O.

The intersection of the direction of these forces will therefore be the middle point M of the line A C.

Further, if M N be drawn perpendicular to A O, and the length M N made proportional to the length A O, and N R drawn perpendicular to C O, and made similarly proportional to the length C O, then M R will be the resultant of all the pressures acting on the quadrant of the ellipse, to the same scale as M N, N R; and the triangles M N R, A O C, will be similar, and have equal angles, and M N being perpendicular to A O, M R will be perpendicular to A C. That is, the resultant M R is at right angles to A C, and passes through its middle point M.

The pressures on the other quadrants of the ellipse may be considered as supplying forces at A and C to hold the quadrant A B C in equilibrium. The force at A will be a force equal to M N, acting perpendicularly to A O, and that at C a force R N, acting perpendicularly to C O. As the directions of these forces do not intersect one another in the line M R, but in a point D outside it, they cannot of themselves balance the force M R.

But the cohesion of the metal supplies the force necessary to produce equilibrium, and the internal stress will be measured by the force so supplied.

Equilibrium would be produced by the addition at A of a twisting couple equal to M N × E D, where E is the point of intersection of C D parallel to A O with M R. If E A′ be drawn parallel to C O, cutting A O in A′, the addition of this twisting couple at A would transfer the force M N parallel to itself to A′, and there would be equilibrium, since then the directions of the forces M N, R N would intersect one another in the line M R.

In like manner, drawing A E′ parallel to C O to cut M R in E′, if a twisting couple equal to R N × D E′, which is equal to the above couple M N × E D, were added at C, the force R N acting there would be transferred parallel to itself to C′, and the direction of the forces at A and C′ now intersecting one another in the line M R produced, equilibrium would again subsist. And thus, taking any point A″ between A and A′, and drawing A″ E″ parallel to O C, and E″ C″ parallel to O A, if a couple represented by M N × A A″ were added at A to transfer the force there to A″, and this couple being equal to R N × C′ C″, a couple equal to R N × C C″ would have to be added at C to transfer the force there to C″ and to produce equilibrium, the two added couples being together equal to the couple M N × E D.

Any number of curves of equilibrium therefore can be drawn to pass through points in A A′ and C C′, each curve being subject to the condition that A″ being one point, the other point C″ is determined by drawing A″ E″ parallel to C O to cut M R in E″, and from E″ drawing E″ C″ parallel to A O to cut C C in C″.

Now, since the caisson is symmetrical, each quadrant has the same amount of pressure on it, and therefore the tangents to the curve of the caisson at A and C must be at right angles to one another both before and after strain; that is, the condition (3) must be satisfied, or

$$\Sigma (M) = 0$$

between the points A and C.

This is also the only condition, as the caisson is at liberty to change its form, and cannot be considered as of invariable span.

To draw the curve of equilibrium, divide the quadrant C B A into any number of equal parts, ten in the figure, and at the centre of each part draw the normals $p_1\,q_1$, $p_2\,q_2$, &c., which will be the directions of the pressures acting on the elementary arcs. From the point R set off R r_1 parallel to the normal at p_1, and equal in length, to the same scale as M N, N R, to the pressure on one of the elementary arcs. From the point r_1, thus found, set off $r_1\,r_2$ = R r_1 and parallel to $p_2\,q_2$, and continue this construction, which will terminate at the point M.

Then if the points r_1, r_2, &c., be joined with N, N r_1, N r_2, &c., will represent the amounts, and be parallel to the directions, of the curve of equilibrium at the different points. To draw the curve, from C″ draw C″ q_1, parallel to O A, to cut $p_1\,q_1$ in q_1; from q_1 draw $q_1\,q_2$, parallel to N r_1, to cut $p_2\,q_2$ in q_2, and continue this construction, which will terminate by the last line drawn passing through the point A″, and having the direction A″ E″.

The point C″ was assumed tentatively, and the values of M found from it. These were the lengths N r_1, N r_2, N r_3, &c., multiplied by the perpendiculars on the directions of these forces at q_1, q_2, q_3, &c., from the points p_1, p_2, p_3, &c.

The position of C″ was then altered until the line was obtained which satisfied the condition

$$\Sigma (M) = 0.$$

In this instance, the pressure per square foot for a depth of 20 feet of water being ·56 ton, for 1 foot in height of the caisson,

The force M N is	7·14 tons,
and the force N R is	4 ,,
The bending moment at A is	8·9 foot tons,
,, ,, at C is	6·6 ,,

Fig. 16 shows all the details of the construction, as explained above, for one of the quadrants.

The method of construction shows that when the eccentricity of the ellipse is small the curve of equilibrium is very nearly a circle, whose radius is the mean between the major and minor semi-axes of the ellipse. It follows from this that, if the shape of a boiler is not truly cylindrical, there may be considerable transverse, in addition to the tangential, stress; and if the deviation from the exact circle were greatest at the riveted joints, the stress would be greatest at the weakest parts. It has already been shown (p. 77), that when the curve of equilibrium touches the surface of an arch of rectangular section, the stress on the metal at the surface is quadrupled. The shell of a cylindrical boiler is an arch of this section, in tension instead of in compression, and therefore at an ordinary lap joint, or at any part where the deviation of form from the true circle amounts to only half the thickness of the plating, provided the deviation extends some little distance in the direction of the length of the boiler, the stress at the surface of the metal is four times that due to the pressure of the steam. This important result, showing how greatly a boiler may be weakened by an incorrectness of form too slight, especially if the boiler be made of steel, to be detected by the eye, is not generally known, so far as the Author is aware. There can be little doubt that incorrectness of form, the evidence of which is destroyed when a boiler explodes, is one of the chief causes of many of the boiler explosions which occur, from time to time, throughout the country.

As the circle is the curve of equilibrium for uniform normal pressure, it might at first sight be thought that it would always be the curve of equilibrium; but an inspection of the figure will show that this cannot be the case. To illustrate the nature of the equilibrium, two of the elementary arcs at p_2, p_3 have been supposed to move parallel to their original positions until the curve of equilibrium passes through their centres. The equilibrium is not disturbed by this movement, but it is obvious that the directions of the forces acting on the arcs differ considerably from the normals to the curve of equilibrium. . . . .

Rigid Roof acted on by Wind.

In order to show the capacity of the method above explained to deal with complex cases of structure, the next example chosen is the roof of the St. Pancras station. The form differs from both the circle and the parabola; the section of the rib varies to some extent near the springing; and, as the roof will be considered to be strained not only by its own weight, but by the side pressure of the wind, the case is also one of oblique forces. The particulars from which Figs. 17 and 18 (Plate 3) have been prepared were taken from the description of the roof given by Mr. W. H. Barlow, in the Minutes of Proceedings of the Institution of Civil Engineers, vol. xxx., p. 78.

Each principal or rib consists of a lattice girder of equal top and bottom flanges, and the neutral line is therefore in the middle of the rib, and is represented on the figure by the centres of the small circles. This neutral line has been divided into forty equal parts. At the centre of each of these divisions a vertical line has been drawn to the level of the base line, and a weight has been supposed to act at each of these centres, equal to the weight of the roof for the length of that division, and for 1 foot longitudinally in the line of the station. That is, since the length of each of these divisions measured along the neutral line is 8·7 feet, the weight has been taken at 8·7 square feet of roof, added to 8·7 feet run of the weight of the rib. This weight is not the same for each of the divisions; the weight per square foot of the lower portion, which is boarded and slated, having been taken, exclusive of the weight of the rib, at twice the weight of the upper or skylight portion.

For the two divisions at the springing, the weight is that of the rib alone, which is heavier below the part where the lattice girder terminates.

Underneath the lattice girder the value of I for the rib has been taken at double of that for the lattice girder. The base line or termination of the divisions has been placed at that point of the rib, near the bottom, beneath which no appreciable curvature or movement from stress could possibly occur.

The following are the weights which have been assumed:

	Per Square Foot.	On One Division.
Skylight portion	29 lbs.	252 lbs.
Boarded and slated portion	47 „	420 „
Lower part of rib	..	222 „

From these weights the lines on the lower diagram, Fig. 17, have been drawn. They represent the curves of equilibrium with the weight of the roof only. The line (*a*), corresponding to the rib hinged at the crown, and the line (*b*), corresponding to the rigid rib with the ends kept from spreading, were useful in fixing the position of the line (*c*), which is the curve of the rigid rib with the ends fixed. This latter line shows the actual stresses on the rib. It will be remarked that this line is contained everywhere within the depth of the rib, the neutral line of which it crosses and recrosses several times, the greatest deviation being inconsiderable. The neutral line of the arch rib therefore differs but slightly from the curve of equilibrium, and the transverse stresses arising from the weight of the roof itself are very small.

In Fig. 18, the horizontal force of the wind has been taken at 40 lbs. per square foot, and has been treated in the following manner:—From the upper and lower edges of the back of each division horizontal lines have been drawn, the vertical distances between which, in feet, multiplied by 40 lbs., give the total horizontal force of the wind acting on the different divisions for 1 foot longitudinally of the roof. Each horizontal force has then been decomposed into an effective part, normal to the curve of the roof, and a non-effective part tangential to this curve. The effective part, passing normally through the centre of the division, has been decomposed into a horizontal and vertical component. The first has been considered as acting horizontally at the centre of the division, and the second as acting vertically there, and forming an addition to the weight of the division.[1]

The construction for this decomposition of forces is shown at the bottom of the Fig., to a scale of 100 lbs. to the inch. The total horizontal forces of the wind O 7, O 8, &c., are laid off for the different divisions on the line O X. From the points 7, 8, &c., perpendiculars are let fall on the corresponding normal lines which pass through O, the centre of the arch rib. The lengths of these perpendiculars represent the lost or non-effective forces, and the distances from the feet of the perpendiculars to O, the normal or effective forces. Perpendiculars let fall on the line O X from the ends of the normal forces determine the horizontal and vertical components of these forces.

The directions of the forces acting at each division were then found by laying off to the same scale vertical lines from the ends of the normal forces, each equal to the weight of the division of the roof to which it corresponded, as shown by the figures of reference. Lines joining the point O with the upper ends of these verticals gave the directions of the forces at each point, and the full black lines which pass through the centre of each division are drawn parallel to these directions.

Having thus found the force acting on each division, and its direction, the resultant of the whole of these forces was then ascertained as follows:

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[1] There is reason to believe that the law of resistance here assumed, viz., that of the squares of the sines, errs in excess of the truth. The construction is therefore a safe one, and the results would probably be approximately true for a considerably greater pressure of wind than that stated in the text.

By taking moments with respect to the base line for each of the effective horizontal forces, their resultant or sum is equivalent to a force of 771 lbs. acting horizontally at a point 61·8 feet above the base line. In like manner, by taking moments with respect to A of the vertical forces, their resultant is equal to a force acting vertically of 14,383 lbs. at a point distant 114·5 feet from A, or 5·5 feet from the centre towards A.

Combining these horizontal and vertical forces by construction, it was found that the resultant of the whole acted in the line R R, which cuts the neutral line of the arch rib in a point C nearly midway between the centres of the divisions 19 and 20.

In like manner, the resultant P P of the forces acting between C and A was found, and the resultant Q Q of those acting between C and B.

As the point C is about $\frac{1}{10}$th of the length of a division distant from the point midway between the centres of divisions 19 and 20, $\frac{1}{10}$th of the weight of division 20 was added to the vertical force at division 19, and deducted from that at division 20, in order to make the calculation of these forces correct.

The direction of the thrust at C was then determined by the method of drawing the curve of equilibrium for oblique forces. As a first approximation, the curve was assumed to pass through the centre of the arch rib at the crown. A point in the line R R was found such that when it was joined by straight lines with the points A and B, which straight lines cut the directions of P and Q in the points E and F, the line E F passed through the centre of the rib at the crown, and gave the direction of the thrust there for the rib considered as hinged at the top. The lines E A, F B were then the direction of the thrusts at A and B. The length E *p* was then cut off on the line E P proportional to the force P. From *p* the line *p k* was drawn parallel to E F, cutting A E in the point *k*, and the length E L = *p k* was laid off on the line E F from the point E, thus fixing the point L.[1]

The force diagram was then constructed by drawing to scale (3,000 lbs. to the inch), from the point L, the line L *a* equal to the force acting on the division 19, and parallel to its direction: from the end of this line the length *a b* was drawn equal to the force at 18, and parallel to its direction, and so on, the end of the last line coinciding with the point *k* in the line A E.

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[1] A somewhat simpler construction is explained at page 113. See Note, p. 114.

Lastly, the curve of equilibrium was constructed by drawing from the point p_1, where the line of force at 19 cuts the line E F, the line $p_1 p_2$, parallel to E a, cutting the direction of the force at 18 in the point p_2, from p_2 the line $p_2 p_3$, parallel to E b, cutting the direction of the force at 17 in p_3, and so on, until the construction terminated by the last line drawn coinciding with the line A E, and therefore passing through the point A.

Having thus drawn the curve of equilibrium for the arch hinged at the crown, as shown by the dotted line (a), it was found that this line almost exactly satisfied the condition

$$\Sigma (M \cdot y) = 0;$$

the raising of the line at the crown, in order to exactly satisfy this condition, as shown by the upper dotted line (b), being scarcely perceptible. Thus the curve for the rib supposed rigid, and the feet kept from spreading, was obtained.

The curve for the rigid arch with the ends fixed was then constructed after a few preliminary trials, and is shown by the dotted line (c). The springing points of the curve requiring to be raised to A′ and B′, and the vertex to be lowered, to satisfy (3) and (6); the point of intersection of the thrusts at A and B with the line R R was altered slightly, and therefore also the position of the line E F, the points E and F being changed to E′ and F′. To avoid altering the force diagram, the line L E″ was drawn parallel to E′ F′, and k E″ parallel to A′ E′, thus fixing the point E″, and the curve of equilibrium was then constructed by drawing the lines parallel to E″ a, E″ b, &c., instead of E a, E b, &c. A similar construction was followed for the other point F.

In drawing these curves, as the directions of the forces at 6, 7, 8, &c., were not vertical, allowance for this had to be made in the values of M. Vertical lines were therefore drawn on the force diagram through the points a, b, c, &c., to cut the line E L, and any point, as (m), was treated as if it formed part of a diagram, where the lines $a\,b$, $b\,c$, $c\,d$ were vertical, and the thrust therefore E m', instead of E L; the lengths of the vertical lines $a\,\beta$, $a\,\gamma$ corresponding to that point and representing M were multiplied by the ratio $\frac{E\,m'}{E\,L}$, before being put in the summation, and a similar corresponding ratio was used for the other points, where the forces were not vertical.

Referring to the line (c), it will be observed that a maximum stress occurs near the middle of the 11th division, at which point the compressive force F is 1·36 tons per square inch, and the compressive stress on the upper part of the rib caused by the bending moment is 2·72 tons per square inch, making together a compressive force on the upper part of the rib of 4·08 tons per square inch.

The other maximum stress occurs at or near the centre of division 36, and is in like manner 1·88 ton per square inch for F, and 2·26 tons per square inch for the bending moment, giving together a compressive force at the under part of the arch rib of 4·14 tons per square inch.

The bending moments or transverse strains to be overcome in producing fixity of the rib at the springing are:

At the point A—

(Horizontal thrust = 42·2 tons) × 12·4 feet = 522 foot tons;

and at the point B—

(Horizontal thrust = 52 tons) × 12·4 feet = 643 foot tons.

The difference between these horizontal thrusts is the effective horizontal pressure of the wind on the space between the ribs.

Rigid Arch Braced and acted on by Wind.

When, as in the case of many roofs supported on walls or pillars, the abutments are not constructed to withstand the thrust of the principals, and a horizontal tie-bar becomes necessary, this is generally raised above the level of the points of support, either for the sake of headway or for appearance, and its ends are connected with the apex and points of support by inclined tie-rods. The curve of equilibrium, including the action of these braces, can still be drawn, and will generally differ in form from the curve of continuous curvature already examined.

Taking the simple form of bracing shown by the full lines on Fig. 19, Plate 3A, and drawing the lines D F, E G, at right angles to the lines A C, B C, through their middle points K and L, the curves of equilibrium for different positions of the ends D, E, of the tie-bar may be compared by assuming these points to be always at the same level, and to move along the lines D F, E G. If the points D and E are situated in the line A B, the curve of equilibrium passing through the points A, C, B is the same as that found for fixed abutments, by the process already described. As the tie-bar is raised above the level of A B, it appears, by the construction explained a little further on, that the strain on it is increased in the ratio of C M to C N, and the strains on the ties A D, D C are also increased. The curve of equilibrium changes its form to that of a pointed or Gothic arch A F C G B, the tangents to which, at the apex C, intersect one another in an angle. This useful and economical form of roof is deserving of consideration, and is intended to be used, for the roof of the new joint station at Bristol, by Mr. Francis Fox, M. Inst. C.E. The curve becomes flatter and the strains are increased as D approaches K. The principals of a roof, if constructed to these curves, would be without transverse strain if loaded equally on each half of the span; but if an additional weight, or force of wind, be supposed to act on one side A C, and not on the other. the curve of equilibrium would change to some other curve A F′ C G′ B. The point F′ would be further from K than F, and the point G′ nearer to L than G. If the neutral lines of the curves of the principals were originally A F C G B, there would then be an amount of positive or negative transverse strain, measured by the pressure along the curve multiplied by the perpendicular on the tangent, as already explained.

The curve has been assumed to be drawn so as to pass through C, and the transverse strain is, therefore, zero at that point: this amounts to supposing the arch to be hinged at the crown. If it is made rigid there, the curve A F′ C G′ B must satisfy the condition of invariability of span. In order to do this, the curve, drawn by the method described in the former part of this Paper, will pass a little below the point C, and the strain there will tend to increase the curvature.

If the middle points of the principals be directly connected to the points D and E, the rib may have any other shape, as A P″ C Q″ B (Fig. 20, Plate 3A), and the transverse stress will be zero at A, P″, C, Q″, B if the rib be considered as hinged at these points.

The curve of equilibrium corresponding to the position of the points D and E in this figure being A P C Q B, if the points P″, Q″, be farther from D than P and Q, the connections P″ D, Q″ E, will be ties; but if these points are nearer to D and E than P and Q, as at P′, Q′, the connections P′ D, Q′ E will be struts. In any case, curves of equilibrium A R P″ S C Q″ B, A R′ P′ S′ C Q′ B can easily be drawn, and are the forms which the neutral lines of ribs ought to have in order to be without transverse strain if loaded equally on each half span. These curves are concave to the straight lines A P″, P″ C, &c., A P′, P′, C, &c., and the amount of their separation from these lines depends on the weight and arrangement of the loading.

If an additional load or force of wind be supposed to act on one side A C, and not on the other, the curves of equilibrium have their curvatures increased on the side A C, and diminished on the other side C B. Were the ribs or principals made to the curves of equilibrium A R P″, &c., there would thus be slight transverse stresses, which would be zero at the points A, P″, C, &c., and increase to a maximum at the middle of the distances A P″, P″ C, &c. These stresses would be of opposite signs on opposite sides of the crown C.

If the rib be supposed to be made rigid throughout, it appears to the Author that in the event of unequal loading, the rib will be in the state of a curved continuous beam of four spans; and the transverse stresses, as compared with those on the rib supposed jointed at A, P″, C, &c., will, as for an ordinary continuous beam, be reduced to about one half; the stresses at P″, C, and Q″ having a contrary sign to those at the middle points of the distances A P″, P″ C, &c.

In addition to the transverse stresses brought on the ribs by unequal forces acting on the two sides of the span, the stresses on the other parts of the frame will be altered. The following construction shows the method of drawing the curve of equilibrium for the braced arch acted on by oblique forces, and of ascertaining the stresses on the other parts.

Referring first to Fig. 19, where the points D and E are unconnected with the principals; having drawn an approximate circular arc for the curve of equilibrium passing through A and C, divide this arc into a convenient number of equal parts, and draw lines $p_0\,q_0$, $p_1\,q_1$, &c., through the centre of each division in the directions of the forces acting on each of these divisions, as already explained for the roof of the St. Pancras Station.

The upward pressures at A and B may be found by taking moments round B and A of all the forces acting on the structure, including the force of the wind, supposed to act on A C, and the forces at A and B necessary to equilibrate this. If the span of the rib be invariable, or the ends be fixed in position, but not in direction, the forces necessary to balance the effect of the wind on A C, are—

(1.) A horizontal force at B acting in the direction B A, and equal to the total effective horizontal force of the wind.

(2.) Upward vertical forces at A and B, of such amounts as will equilibrate the effective vertical force of the wind.

(3.) A couple whose moment is $W \cdot w$, if W be put for the effective horizontal force of the wind, and w for the vertical height of its centre of action above A. Calling s the length of the span

A B, this couple is equivalent to an upward vertical force $W \frac{w}{s}$ acting at B, and an equal vertical force acting downwards at A, since the horizontal force of the wind cannot alter the sum of the upward forces at A and B. The moment $W \cdot w$ of these forces must be added in taking moments round A and B. If the rib is only fixed in position at one end, as at A, and the other end B is on rollers, the force equal and opposite to W will act at A instead of at B. On this latter supposition, the stresses on the ties are increased.

The stress on the horizontal tie-rod D E is found by taking the moments round C of the forces to the left of C, including the force of the wind. The accuracy of the results may be tested by taking moments to the right of C, including that due to the external forces already mentioned.

In order to draw the diagram of forces; on the horizontal line A B, and with any convenient scale, make A *a* equal to the horizontal strain on the tie-bar, ascertained as above, and draw the line *a b* parallel to D C, cutting A D in *b*; *b a* will then be the stress on D C, and A *b* on the tie A D. From the point *b* draw *b* T vertical, and equal to the upward pressure at A. A T will be the resultant of the forces A *b*, *b* T, acting at A, and will be the direction of the tangent to the curve of equilibrium at the point A. The force diagram is then made by drawing Tr_0 equal to the force at p_0, and parallel to its direction, $r_0 r_1$ equal and parallel to the force at p, and continuing this construction until the last point, k, is arrived at. Drawing kf horizontal and Tf vertical, kf is equal to the total horizontal force of the wind, and Tf to the sum of the vertical forces acting on the rib between A and C, including the vertical components of the force of the wind.

The curve of equilibrium is constructed by drawing Ap_0 in the direction A T to cut $p_0 q_0$ in the point p_0, from p_0 drawing $p_0 p_1$ parallel to Ar_0 to cut $p_1 q_1$, in the point p_1 and continuing this construction for the other points. The last point should be coincident with C, and the tangent to the curve there should be parallel to A k.

For the other side of the span, having made $B a' = A a$, and drawn $a' b'$ parallel to the tie E C, draw $b' T'$ vertical, and equal to the upward pressure at B, and $T' T''$ horizontal, and equal to the external force necessary at B to maintain equilibrium. The forces on this side being all vertical, draw $T''f'$ vertical, and equal to the sum of the forces acting on the rib from C to B. T'' B will be the direction of the tangent to the curve of equilibrium at B, and f' B parallel to its direction at C; and by dividing $T''f'$ into portions representing the forces on each of the divisions of C B, the curve of equilibrium can be drawn between B and C.[1]

In Fig. 20 (Plate 3A), where the points D and E are connected to the middle points of the principals, the upward pressures at A and B, and the stress on the horizontal tie-bar D E being ascertained as before, the stress on A D is found by taking moments round P″ to the left of P″; the moment of the force along A D balancing the difference between the moment of the upward pressure at A, and the moments of all the forces, including the force of the wind, acting on A P″. Make A b equal to the stress thus found, and A a equal to the horizontal stress on the tie-bar D E. Joining b, a, $b\,a$ will represent the force to be balanced by the forces of D P″ and D C. If $\beta\,a$ be drawn parallel to D C, and $\beta\,b$ parallel to D P″, $b\,\beta$ will be the stress on D P″, and $a\,\beta$ the stress on D C. From b draw b T vertical, and equal to the upward pressure at A, and construct from the point T the diagram of forces for the part A P″. From the last point r_5, so obtained, draw r_5 R equal and parallel to $b\,\beta$, and continue the construction from the point R for the part P″ C. The curve of equilibrium is then constructed from the force diagram as before; A T and A r_5 being parallel to the directions of the tangent to the curve A P″, at the points A and P″, and A R, A k, parallel to the directions of the tangents to the curve P″ S C, at the points P″ and C, through which points the curve of equilibrium passes.

For the other side C B, the construction is made in the same manner, care being taken to include the effect of all the forces necessary to maintain equilibrium as already explained.

Figs. 19 and 20 are drawn to scale, and represent a roof of a rise equal to one-fourth of the span, with the ends fixed in position, but not in direction; or without expansion rollers under the end of the ribs. The diagrams of forces on each side of Fig. 19 are also drawn to scale, and show the amounts of the forces acting on one of the ribs, which are supposed to be 20 feet apart, the weight of the roof to be 10 lbs. per square foot, and a gross horizontal force of wind of 40 lbs. per square foot, acting on A C. This force has been decomposed into effective horizontal and vertical forces, in the same manner as described for the roof of the St. Pancras Station, and the curves of equilibrium on the diagrams are assumed to pass through the point C, the apex of the roof.

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[1] By supposing the points D and E to be in the line A B, this method of construction may be used for cases like the St. Pancras roof, and is more simple in some respects than the method referred to in the commencement of this Paper.

For Fig. 20, forces equivalent to those for Fig. 19 are supposed to act on the roof, and the diagrams of force are drawn both for the curve A P″ C Q″ B, and also for the curve A P′ C Q′ B; those for the latter curve being indicated by a small $_0$ placed before the reference letters, as $_0$T.

A comparison of these diagrams shows that the stresses are much smaller for the first form than for the second form of roof. The perimeter of the former is, however, a little longer than that of the latter, and although this will slightly increase the surface of the roof, the diminution of the stresses will, on the whole, considerably lessen the cost.

On Fig. 20, the full curved lines are the curves of equilibrium for the roof supposed to be acted on only by symmetrical vertical forces. The curves of equilibrium as altered by the action of the wind, differ so slightly from these as to be nearly undistinguishable on the small scale of the diagram.

EFFECT OF A SMALL ALTERATION OF SPAN.

The span of the arch rib has hitherto been considered as invariable, that being the condition assumed in arriving at Equation (6). But there are several circumstances which induce real or virtual alterations of span; and although these alterations are small, as compared with the length of the span, yet the fact of their occurrence shows that the condition of absolute invariability of span cannot be held to represent the state of an arch rib under strain. The smallness of the alterations, however, allows of the use of the principle of the superposition of small changes; that is, that the total alteration, if small, due to any number of causes, is the algebraical sum of the alterations due to each cause separately.

(1.) By a change of temperature the length of the rib is altered, and its ends, if free, would be displaced, horizontally and vertically, through small, yet measurable spaces, which spaces would be proportional to the amount of change of temperature. If the abutments could be supposed to move through these small spaces, so that their reactions, which existed before the change, could be applied to the ends of the rib with the same intensity and in the same direction as before, the equilibrium would not be disturbed. But as the abutments cannot adapt themselves to these changes, the feet of the arch rib will spread or contract, so as to rest on the same points of the abutments as before, and the span will thus be virtually altered.

(2.) A direct lengthening of the span would be produced if the thrust of the arch forced the abutments farther apart than they were previously to this thrust coming upon them. The amount of yielding of the abutments it is impossible to predict, as it depends on the nature of their foundations as well as upon the bulk and quality of the masonry or brickwork, and there are as yet scarcely any data recorded for existing structures. In a bowstring girder, the lengthening of the tie by stress, or alteration of temperature, corresponds to a yielding of the abutments of an arch.

(3.) The thrust of the arch will compress and shorten the length of the arch rib itself, and will, as appears by the above remark, produce a virtual lengthening of the span. The amount by which the span is lengthened from this cause may be determined by dividing the neutral line of the rib, on a drawing to a moderately large scale, into a number of equal parts, and laying off on each of these parts a length equal or proportional to the length by which that part of the rib is compressed by the thrust. These lengths depend on the amount of thrust and the sectional area of the rib, and will be equal to one another if this area is everywhere proportional to the thrust. The horizontal projections of the lengths may then be found, and their sum will be the horizontal displacement of the end of the rib, or the virtual change of span.

While arches were constructed of masonry or brickwork, it was only thought necessary to measure the amount of settlement of the crown, which might indicate, though it could not separately measure, a yielding of the abutments as well as a compression of the arch ring. Greater precision was immaterial, for, by the number of its joints and the plasticity of the mortar, an arch accommodates itself to its own internal changes and to a slight yielding of its points of support. With cast-iron arches more minute observations are requisite, while for large arches of riveted wrought iron, where the structure approaches in incompressibility to solid wrought iron, it becomes an important practical question to determine how much the stresses on an arch rib may be altered by an assumed small alteration of the span. The process already described, by which the curve of equilibrium can be found so as to satisfy the condition of invariability of span, gives at once the means of ascertaining this alteration of the stresses.

For, in approximating to that curve, values of M are obtained for one or more curves differing slightly from it in position. For any one of these curves, $\Sigma\left(\frac{M}{I}\cdot b\,c\right)$, instead of being equal to zero, is a definite quantity; and this quantity may be substituted in Eq. (4), which, as appears by the remarks on that equation, may be written thus:

$$h = \frac{1}{a} \Sigma \left(\frac{M}{I} \cdot b c \right) \Delta s.$$

The value of h, the horizontal displacement, will thus be obtained for a curve whose apex is higher or lower than that of the curve which satisfies the condition of invariability of span by a small quantity, say d.

If, then, σ be the assumed horizontal displacement, a curve of equilibrium must be found, which, putting σ for h in the above equation, will satisfy the condition—

$$\sigma = \frac{1}{a} \Sigma \left(\frac{M}{I} \cdot b c \right) \Delta s \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Calling δ the height of the apex of this last curve above that of the curve of invariable span, since d and δ are both small, δ may be approximately found by the proportion—

$$h : d :: \sigma : \delta;$$

and the apex of the curve being thus determined, the curve may be drawn, and the process verified by ascertaining whether the values of M will satisfy Equation (13).

Having thus obtained the curve corresponding to the displacement σ, the stresses are the values of M belonging to this curve, and may be compared with those of the curve of invariable span.

To give an idea of the change of stress caused by a given small alteration of span, the case of a parabolic, and approximately of a circular, rib of uniform section and small rise, loaded with a weight uniformly distributed horizontally, admits of easy solution.

Let the semi-span = S and rise = D, σ and δ meaning as above. Also let H_0 be the horizontal thrust for the rib with the ends not displaced, and H_1 the horizontal thrust for the curve of equilibrium corresponding to the displacement σ, and rise $D + \delta$. Taking the origin of co-ordinates at one end of the rib, for any abscissa x, let y be the ordinate of the rib or curve of equilibrium for the thrust H_0, and y' the ordinate of the curve of equilibrium for the thrust H_1.

Then $$y = \frac{D}{S^2} (2 S x - x^2)$$

$$y' = \frac{D + \delta}{S'^2} (2 S x - x^2)$$

and $$M = H_1 (y' - y) = H_1 \frac{\delta}{S^2} (2 S x - x^2).$$

Since the rise is small, Δs may be taken equal to $d\,x$, and it is easily found by integration that

$$\Sigma_0^s\, \mathrm{M}\cdot b\, c\, \Delta s = \int_0^s \mathrm{H}_1 (y' - y)\, y\, d\,x = \frac{8}{15} \mathrm{H}_1\, \delta\, \mathrm{S}\, \mathrm{D}$$

Substituting this value in Eq. (13),

$$\sigma = \frac{8}{15} \frac{\mathrm{H}_1\, \delta\, \mathrm{S}\, \mathrm{D}}{a\, \mathrm{I}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

In this formula $\mathrm{H}_1\, \delta$ is the bending moment at the crown of the arch, which by Eq. (2) may be put $= \frac{t_0}{k_0}\mathrm{I}$, where t_0 is the stress per square inch caused by this bending moment. Also f may be put for the uniform compression $\frac{\mathrm{H}_0}{\mathrm{A}}$ per square inch caused by the thrust H_0. Multiplying the numerator of σ in (14) by $\frac{\mathrm{H}_0}{\mathrm{A}}$, and the denominator by its equivalent f, and substituting $\frac{t_0}{k_0}\mathrm{I}$ for $\mathrm{H}_1\, \delta$,

$$\sigma = \frac{8}{15} \cdot \frac{t_0}{f} \cdot \frac{\mathrm{H}_0\, \mathrm{S}}{\mathrm{A}\, a} \cdot \frac{\mathrm{D}}{k_0}\,.$$

But $\frac{\mathrm{H}_0}{\mathrm{A}} \frac{\mathrm{S}}{a}$ expresses the contraction of a bar of a length S under the force $\frac{\mathrm{H}_0}{\mathrm{A}}$, or, in other words, the approximate horizontal displacement of the end of the arch rib by the force H_0. Calling this ϵ,

$$\sigma = \frac{8}{15} \cdot \frac{t_0}{f} \cdot \frac{\mathrm{D}}{k_0}\, \epsilon,$$

and

$$t_0 = \frac{15}{8} \cdot \frac{k_0}{\mathrm{D}} \cdot \frac{\sigma}{\epsilon}\, f.$$

For an arch rib of 200 feet span, and 20 feet rise, the depth of the rib being 4 feet, and the cross section I, or box-shaped,

$k_0 =$ 24 inches
$\mathrm{S} =$ 1200 „
$\mathrm{D} =$ 240 „

And if f be 4 tons per square inch, and $a = 10{,}000$ for wrought iron,

$$\epsilon = \frac{1200}{10000} \times 4 = \tfrac{1}{2} \text{ inch nearly,}$$

$$t_0 = \frac{3}{2}\, \sigma.$$

If $\sigma = \epsilon$, or the change of span be equal to the displacement of the end of the rib by the compression.

$$t_0 = \tfrac{3}{4} \text{ ton per square inch.}$$

Or, the shortening of the span by the compressive force f will be $\tfrac{1}{2}$ an inch, and the additional stress at the outer surface of the rib at the crown, caused by the virtual lengthening of the span from compression, will be $\tfrac{3}{4}$ ton per square inch.

Again, making

$$t_0 = f$$
$$\sigma = 2\tfrac{2}{3}.$$

Or a yielding of the abutments of $2\tfrac{2}{3}$ inches each would double the stress on the outer surface of the arch at the crown, since the total stress there would be $f + t_0$.

The moment of any horizontal thrust being equal to the moment of the weights,

$$H_0 D = H_1 (D + \delta) = \text{moment of weights.}$$

Substituting the value of δ from this equation in Equation (14), it becomes, writing A q^2 for I,

$$\sigma = \frac{8}{15} \cdot \frac{D^2}{q^2} \cdot \frac{H_0 - H_1}{H_0} \cdot \epsilon;$$

from which it appears that $(H_0 - H_1)$, or the loss of horizontal thrust, is proportional to σ, the extension of the span.

$$\text{And if } H_1 = 0$$

$$\sigma = \frac{8}{15} \frac{D^2}{q^2} \epsilon.$$

In the numerical example which has been chosen, q may be taken $= 24'$, and

$$\sigma = 26\tfrac{2}{3} \text{ inches}$$

would be the movement of each abutment when the arch had no horizontal thrust, but was in the condition of a girder. It is needless to say that the rib would break long before this extension of span was reached, wrought iron not being sufficiently extensible to admit of the theoretical result being obtained.

The change in length of a bar of wrought iron, by a change of temperature of 15°, being the same as for a strain of 1 ton per square inch, and f being 4 tons per square inch, if an arch rib of the above dimensions had its temperature reduced $4 \times 15° = 60°$ below the temperature at which its parts were put together, an additional stress would be caused at the outer surface of the rib at the crown of $\tfrac{3}{4}$ ton per square inch. And if the abutments also yielded each $\tfrac{1}{2}$ inch under the thrust, the stress would be increased from $f = 4$ tons to $4 + 3 \times \frac{3}{4} = 6\frac{1}{4}$ tons per square inch, by the compression of the arch ring, the reduction of temperature, and the yielding of the abutments. The change of temperature may either increase or diminish the stress, according as it is a fall or a rise; but the compression of the arch ring, and the yielding of the abutments, always conspire together to increase the stress. To overcome this action, a margin should be allowed in the factor of safety, or the span of the arch during construction might be made slightly greater than the distance between the abutments; and before the weight of the roadway was allowed to come on the ribs the span could be shortened by wedging or otherwise.

ELASTIC CURVE AND DEFLECTION OF THE CROWN.

The elastic curve, or the curve which the neutral line will assume under the stresses to which the rib is subjected, may be found in the following manner :—

(1.) Supposing the temperature of the rib to change, the length of each of the divisions of the neutral line will be altered by a small quantity, which will be proportional to the length; and the form of the rib, as altered by change of temperature, may be considered to be a magnified representation of its original form. Further, by taking, on a drawing of the neutral line of the arch rib the length of a division to represent the alteration of its length, the drawing itself will represent the changes of the different points by the alteration of temperature. That is, if by applying an appropriate scale the alteration of span by change of temperature be measured by the span itself, the rise of the rib to the same scale will measure the alteration of rise, and the horizontal and vertical displacements of any point of the arch rib by change of temperature may be found by applying the scale to the drawing of the neutral line.

(2.) The compression of the arch rib by the force F will cause all its points to be displaced horizontally and vertically through small spaces, which may be determined by the following construction, which assumes that the sectional areas as well as the forces are not uniform throughout the rib :—The amount of the force F at any point can be ascertained by scale from the force diagram used in drawing the curve of equilibrium; and from this, and the sectional area of the rib, the length by which each of the divisions of the neutral line is altered by compression may be found. Taking any assumed point as an origin, a diagram can then be constructed, by drawing through this point a line parallel to the direction of the neutral line at the centre of the first division, and equal in length to the amount by which the length of that division is compressed by the force F, from the point so found, drawing a line parallel to the direction of the neutral line at the centre of the 2nd division, and equal in length to the amount by which the 2nd division is compressed by the force F. This process is to be continued until the last division is arrived at. The horizontal and vertical displacements of a point in the neutral line of the rib, at the centre of any division, will then be the horizontal and vertical projections of a line on this diagram, joining the origin with the middle of the line corresponding to the compression of that division. By this means the horizontal displacement of the end of the rib by the compression may be ascertained.

(3.) The conditions existing at the ends of an arch rib being given, that is, whether the span is invariable, or altered by a small quantity, namely, the amount of yielding of the abutment, and the alterations produced by compression and change of temperature, and whether the ends are free or 'fixed,' the proper curve of equilibrium to satisfy these conditions can be drawn by the method above described, and the values of M ascertained. The displacements of all the points of the rib by the bending moments M can then be determined by Equations (4) and (5), which may be thus written:

$$h = \frac{1}{a} \Sigma \left(\frac{M}{I} \cdot bc \right) \Delta s$$

$$v = \frac{1}{a} \Sigma \left(\frac{M}{I} \cdot x \right) \Delta s;$$

or, in the case of vertical forces (Fig. F):

$$h = \frac{H}{a} \Sigma \left(\frac{PN \cdot PQ}{I} \right) \Delta s \quad . \quad . \quad . \quad . \quad (15)$$

$$v = \frac{H}{a} \Sigma \left(\frac{PN \cdot AQ}{I} \right) \Delta s \quad . \quad . \quad . \quad . \quad (16)$$

In reference to the limits between which the summations indicated by Σ in these formulæ are to be taken, it is to be remarked that, referring to formula (15), if the summation be performed from A up to B (Fig. F, p. 79), and the result be substituted in this formula, the value of h is the total horizontal spread of the feet of the arch rib, and this spread must be equal to the sum of the displacements of A and B, from the yielding of the abutments and the alterations produced by compression of the rib and change of temperature. Likewise, if the vertex C were considered as a fixed point, the displacement of the point A would be the value of *h* as obtained by performing the summation between A and C, and substituting this in formula (15); and, in like manner, the displacement of B would be obtained by means of the summation from C to B. But the actual displacements at A and B from the causes enumerated above may, and probably will, in most cases differ from the displacements obtained by considering the vertex C as a fixed point. It will not, however, be difficult to find, by a trial or two, such a point, say C′, that the summation from A to C′ being substituted in formula (15), the resulting value of *h* will be the actual displacement of A. This point C′ having been found, since the total spread is equal to the sum of the displacements at A and B, the summation from C′ to B substituted in formula (15) will give for the value of *h* the actual displacement of B from the above causes.

The elastic curve being then referred to the point C′ as an origin, the displacement of any other point as p^{11} may be found by entering the difference between the summation from A to C′, and from p^{11} to C′, in formula (15). The displacement of p^{11} may otherwise be found, as in the first method mentioned in p. 71, by performing the double summation indicated by $\Sigma\,\Sigma\,M\,\Delta\,y\,\Delta\,s$, from C′ to p^{11}, and substituting this in formula (15), instead of the single summation.

Similar remarks to the above apply to formula (16) for vertical displacements.

Having thus found the displacements of the different points, the elastic curve can be drawn through the new positions of the points so displaced, and the deflection of the crown will be simply the alteration in the rise of the arch rib.

In the case of the parabolic or circular rib of small rise, a formula for v may be arrived at similar to that for σ in Eq. (14).

Putting $d\,x = \Delta\,s$, it is found by integration that

$$\Sigma_0^s\,(P\,N \cdot A\,Q)\,\Delta\,s = \int^{\frac{1}{2}s} H_{,}\,(y' - y)\,x\,d\,x = \frac{5}{12}\,H_{,}\,\delta\,S^2,$$

and substituting this value in Eq. (16),

$$v = \frac{5}{12} \cdot \frac{H_{,}\,\delta\,S^2}{a\,I}.$$

Combining this with (14),

$$v = \frac{75}{96}\,\frac{S}{D}\,\sigma,$$

showing that the deflection is in proportion to the extension of span.

For the arch rib of the roof of St. Pancras Station, not acted on by wind, the virtual lengthening of the span by the compression of the arch rib, found by the construction described above, is ·23 inch. Substituting this for h in Eq. (15), and taking $a = 8000$ for riveted iron,

$$I = 46 \text{ sq. inches} \times 36^2 = 59600, \ \Delta s = 8 \cdot 7 \text{ feet, or } 104 \text{ inches,}$$

and the horizontal thrust of the rib 46 tons; the resulting value of $\Sigma(PN \cdot PQ)$, the unit being one foot, is 166. But it appears by Fig. 17, that an alteration of the vertex of the curve of equilibrium (c) by 1 foot, makes an alteration in $\Sigma(PN \cdot PQ)$ of 900, and for an alteration of 166, the vertex of the curve would require to be shifted 1 foot $\times \frac{166}{900}$, or ·18 foot. This is not more than the thickness of the line on the figure, so that the values of M as altered by the compression of the arch rib may still be taken from the curve (c). Making, then, for this curve, the summation $\Sigma(PN \cdot AQ)$ for the half rib, it is found that the $+$ and $-$ values, 423 and 446, are so nearly equal that the sum may be taken as zero.

The deflection of the crown, therefore, will be unaltered by the transverse stresses brought upon the rib by its own weight.

And thus the deflection will be simply the diminution in the rise of the rib, caused by its own compressibility. This, taking $a = 8000$ for riveted iron, is found, by a diagram constructed as already described, to be ·2 inch.

As stated in Mr. Barlow's Paper, the observations made upon the rib itself gave from $\frac{3}{16}$th to $\frac{1}{4}$th inch for the deflections, so that the agreement with calculation is very close indeed.

Had the rib not been fixed at the ends, the value of $\Sigma(PN \cdot AQ)$, estimated from the curve (b), would have been $-$ 1648, the unit being one foot; and the deflection, calculated by substituting this value in Eq. (16), would have been 2·4 inches, in addition to the diminution of rise caused by the compression of the arch rib.

Direct Measurement of Stress.

It would be somewhat difficult, by ordinary methods, to test satisfactorily the stresses on an arch rib, so as to compare them with calculation. Observations on deflection would give some information, but a model would necessarily be on a comparatively small scale, and the rib would require to be curved, yet as much as possible without initial stress.

The Author thinks that when it is desirable to know the stress which any part of a structure or model is sustaining, it is possible to ascertain this by direct observation.

The principle which underlies all investigations of stress, and which has been established by experiment, is that, for working stresses, extension or compression is proportional to stress; or, in other words, the nature of the material, and the extension or compression of a given length of it being known, the amount of stress can be at once determined.

In wrought iron, the extension on a length of 50 inches, with a strain of $\frac{1}{5}$th ton per square inch, would be $\frac{1}{1000}$th of an inch. This length is quite within the reach of exact measurement by means of magnifying glasses; since, with a power of 50, it would be equivalent to measuring $\frac{1}{20}$th of an inch by the naked eye. If two microscopes, magnifying even less for iron, and considerably less than this for timber, were attached to a bar of the same material as the structure to be tested, so as to eliminate the effect of alterations of temperature, about 50 inches long, and were each capable of being moved a short distance along the bar by a micrometer screw, it is believed that stresses of $\frac{1}{5}$th ton per square inch could be read off with certainty. For this purpose, it would only be necessary to furnish the eye-pieces of the microscopes with finely-divided scales. By means of the micrometer screw, having set the zeros of the scales nearly to coincidence with two marks made on the iron, at the part where the stress was expected to be the greatest, the readings of the scales before and during the testing would give the stresses in the most direct manner.

The exact value of the scales, in terms of the stress, could be determined, if necessary, by a preliminary experiment on the direct extension of a piece of the material.

By this means, the stress could be measured at that part of the structure where it was most important to measure it.

It might be said that, owing to the want of homogeneity of the material, the short piece, on which the observation was taken, would differ in extensibility from the part of the structure it was desirable to test. But this objection is not of much force, since experiments on pieces of moderate length, show that the rate of extension for working stresses does not vary, in different specimens of the same material, to nearly the same extent as the breaking weight, which is probably determined by the imperfection of a portion of the material of very limited dimensions.

measurement of the small extensions or compressions here might even be useful in another way.

It is found that the modulus of elasticity, and the breaking weight, are each greater for wrought than for cast iron, and greater for steel than for wrought iron; and it may therefore be said, though in a very general way, that the less the extensibility, the greater the breaking weight.

This view is borne out by Fig. 21, Plate 3A, which shows some results obtained from experiments when examined under this aspect.

Referring first to the experiments on tensile strain, which are distinguished on the figure by small dots, those for steel and wrought iron have been taken from the "Experiments on Steel made by a Committee of Civil Engineers" (1868–70), and those for cast iron from the Report "On the Application of Iron to Railway Structures" (1849). The fair line A A has been drawn to represent the average of all these experiments.

It will be remarked that wrought iron has about one half the extensibility, and fully three times the strength of cast iron; and that although the strength of steel varied considerably in the different specimens tried, the extensibility was very nearly the same for all—meaning by extensibility, the alteration of the unit of length by a force of one ton per square inch.

The remaining particulars on Fig. 21 have been taken from the experiments on cast-iron bars broken by transverse strain, which are recorded in the second of the above-mentioned Reports, and the fair line B B has been drawn to represent average results.

For each experiment, the extensibility was taken as the reciprocal of the modulus of elasticity, in the ordinary formula which connects the central deflection of a bar with the weight of the load acting on it. The breaking stress per square inch was considered to be that on the outside surface in the middle of the bar, as deduced from the well-known formula, which connects the load, taken as the breaking weight, on the middle of the bar, with the tension on the outer surface in the middle of the span.

It has long been known that the breaking stress, deduced in this manner, was very much higher than any result that could be obtained from experiments on direct tensile strain; and this fact, whatever may be its cause, accounts for the want of coincidence between the lines B B and A A. Mr. W. H. Barlow has examined this subject minutely,[1] and has arrived at the result, that in cast iron the breaking stress, deduced from transverse fracture, is about two and a quarter times that obtained from fracture by direct tension.

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[1] *Vide* Philosophical Transactions, vol. cxlv., p. 225, and vol. clxvii., p. 463.

If the vertical ordinates of the line B B be reduced in this ratio, the line C C is the result; and this line, as will be observed, is nearly coincident with the line A A.

The subject of the connection between the breaking weight and the extensibility is deserving of further examination, as the experiments on wrought iron are few, and have probably been made on good specimens, whereas it would be desirable to examine experiments made on fair commercial samples; and should it be found, that as an inferior kind of wrought iron approaches to cast iron in its physical structure and breaking weight, it also approaches it in the scale of its extensibility for working stresses, an observation of the kind above mentioned, taken where the strain could be accurately determined by calculation, would give the means of ascertaining the quality of the iron used in a structure.

The communication is accompanied by a series of diagrams, from which Plates 3 and 3A have been compiled.

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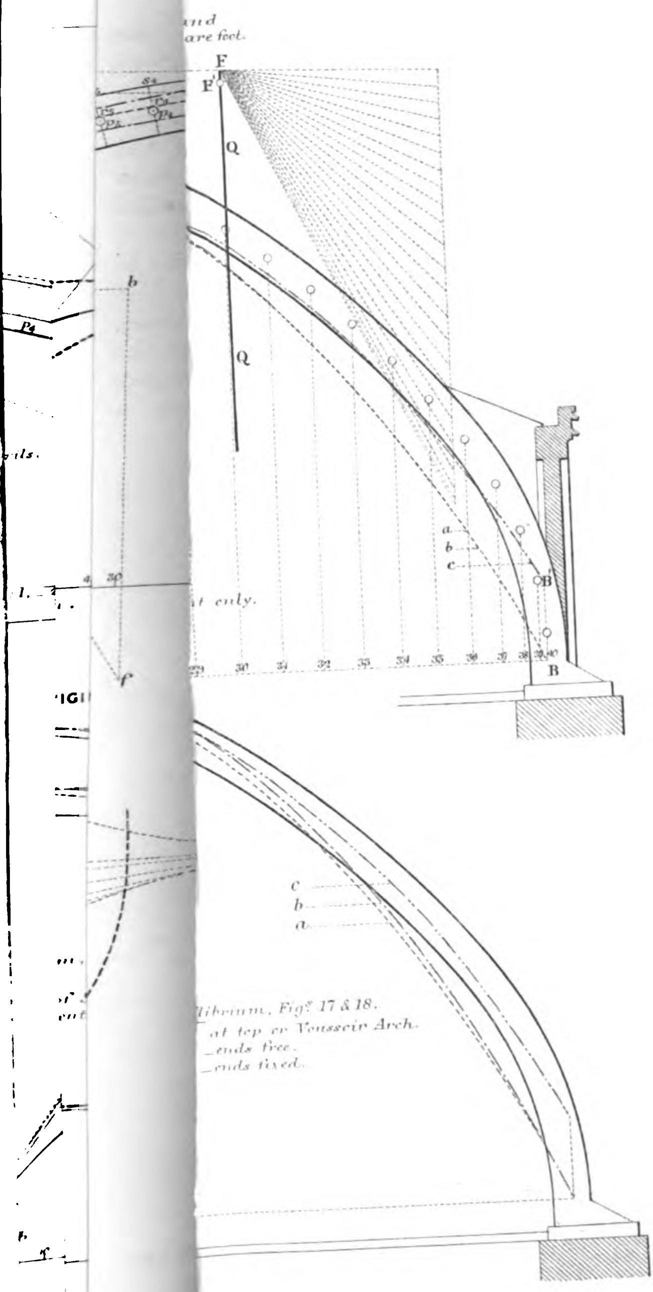
PLATE 3.



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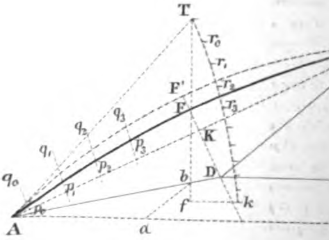
BELL, BROS LITHRS CASTLE ST HOLBORN

RIGID ARCH B

Fig: 1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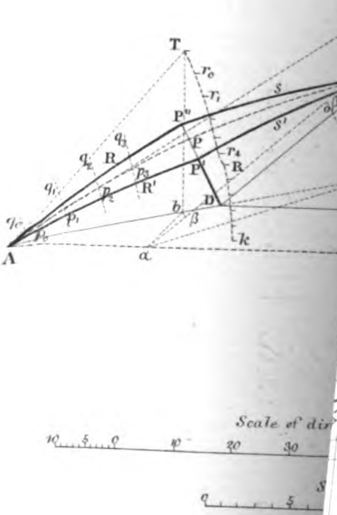
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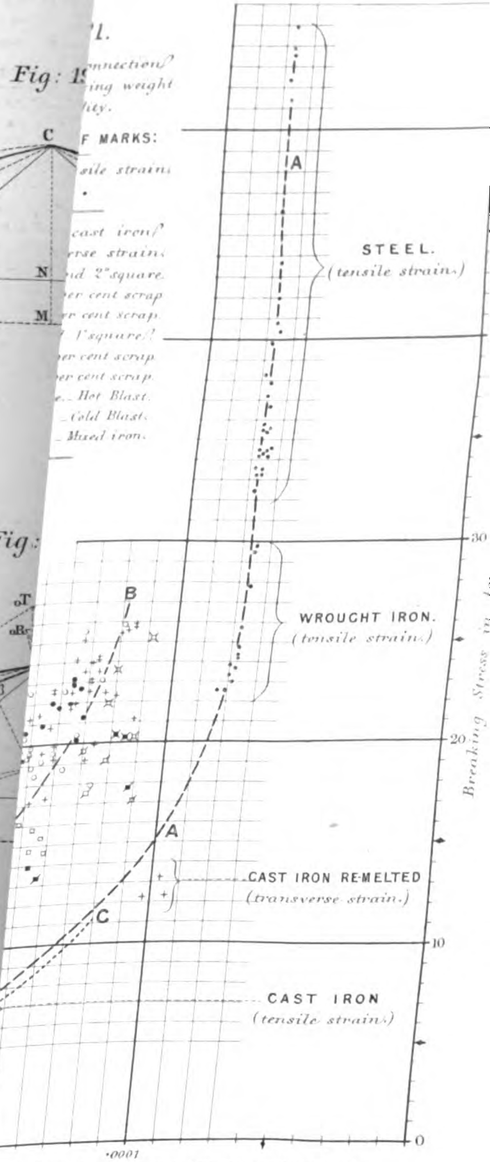

...it of length with one ton per square inch.

Minutes of Proceedings of The Instituti

KELL, BROS LITH^RS CASTLE ST HOLBORN

M. J. **Gaudard**, in a communication to the Secretary, remarked that the question of the resistance of arches, so difficult at first sight, was becoming more and more simplified, and had entered a phase of progress which would greatly facilitate its practical application. He had at once perceived with satisfaction, that the fundamental bases of the theory, such as were admitted by Mr. Bell and by the French authorities, were in perfect harmony. This fundamental concordance, manifest through the diversity of methods of demonstration and of research, should be an assurance that the theoretic truth had been well ascertained. But far from saying that there was nothing more to be done, the need of rendering easy the practical applications was strongly felt, and Mr. Bell had greatly contributed to progress in this direction by introducing, to a considerable extent, graphical representations.

The example given in Appendix No. I. of M. Gaudard's Memoir "On Metal and Timber Arches" had been treated directly by the employment of the formula for the thrust of rigid arches. It was only incidentally that he had indicated, in Section 15,[1] how the curve of pressures was deduced from the result of calculation already made without the aid of this representative line. Mr. Bell proceeded otherwise; he made the delineation of the curve of equilibrium play the principal part, with a view to substitute the graphic and easily-intelligible method for the more laborious algebraic processes, which were so often thought repulsive to practical Engineers. With this object, he remarked that among all the curves of pressure that could be constructed by varying their culminating point, it was possible to investigate, by the system of trial and error, that which would assure the invariability of the chord of the arch, as regarded the rigidity or resistance to flexure. For an arch *encastré* at the abutments, it was known that the required curve would generally deviate from the points of origin of the mean fibre: it included a new arbitrary element; a new condition also was joined to the preceding, to determine the problem. Much as M. Gaudard was still wanting in a personal acquaintance with these new processes, he was not the less convinced that they should be of a nature to satisfy engineers, who had a just predilection for graphic methods, which were capable of resolving complicated cases of various problems of resistance, of the removal of earth, &c., with an ease unknown to algebraic calculation. M. Culmann, Professor at the Polytechnic School at

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxi., p. 116.

Zürich, had treated this branch of science in an excellent work, "Die graphische Statik."[1]

In comparing, as a test, formula No. 9 of the Paper with formula No. 17 of his own Memoir "On Metal and Timber Arches,"[2] he found the two formulæ were in accordance, provided that, in the latter, the terms containing the factor r^2 were annulled. M. Bresse's formula was more complete than Mr. Bell's, in that, in the calculation of the elastic displacement of the extremity of the arch, not only was the deformation by flexure considered, but also the slight shortening of the mean fibre under the longitudinal pressure. However, as he had said, in section No. 13 of the Paper "On Metal and Timber Arches," and shown numerically in section No. 5 of the Appendix I., the terms suppressed by Mr. Airy and Mr. Bell had but little influence in practice. By neglecting these terms, formula No. 9 furnished an expression of the horizontal thrust, independent of the rigidity or of the moment of inertia of the section supposed constant. Moreover, he might add, that Mr. Bell had not lost sight, small though it was, of the shortening of the mean fibre, since it was treated separately, under the section on the "effect of a small alteration in the span of a rigid arch." He might perhaps be permitted, in conclusion, to raise an incidental question, apart indeed from the theory properly speaking of arches, but which had been suggested by the remarks in the Paper on the voussoir arch. In the resistance of a masonry arch, it did not suffice to know how to find the strains of the voussoirs under certain loads, but it was necessary to ascertain what these loads were. They were not data at once resolvable in mechanical lines, but were only to be treated under a physical form, *i.e.*, under the form of a filling-in of earth, or of a loading composed of pulverulent matters, partaking at once of the nature of solids and of fluids. Generally, it was considered that the body of earth was decomposed into vertical prisms corresponding to each voussoir, on which they were thought to press vertically; but some persons likened the pressure of the earth on the extrados to the normal action of a liquid. Doubtless the truth lay between these two opinions, and the question came under the general theory of the thrust of earths. The theory of Poncelet on this point required

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[1] 8vo. Plates. Zurich, 1866.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxi., p. 86. The correct formula is

$$T = p\rho \cdot \frac{a^2\phi\left(\frac{1}{2} - 5\cos^2\phi - 2\phi\sin\phi\cos\phi\right) + \frac{3}{2}a^2\sin\phi\cos\phi - r^2\sin^2\phi\left(\frac{1}{2}\phi + \frac{1}{2}\sin\phi\cos\phi - \phi\cos^2\phi\right)}{a^2 B + r^2\sin^2\phi\,(\phi + \sin\phi\cos\phi)}.$$

revision; he believed it had been already questioned in recent French writings,[1] but he had not himself had an opportunity of examining these.

Professor E. Collignon remarked, through the Secretary, that, in his view, Mr. Bell proposed to extend to rigid curved structures the method of constructing the curve of equilibrium which was generally only employed for arches and jointed systems. The Author began by applying this method to the masonry arch of the Pont-y-tu-Pridd. The great lightness of this arch, by rendering it sensible to the influence of accidental loading, made it a natural introduction to the study of metallic arches, in which the action of external loads preponderated. He found a new idea in this first portion of Mr. Bell's Paper—the likening the material which filled up the haunches to a liquid of the same density pressing the arch normally. Up to the present time, only vertical strains had been admitted for this load; but since the law of the transmission of pressures to the heart of massive solids was not known, it would be perhaps well to adopt successively, for the trace of the curve of pressure, the old and the new hypotheses.

Passing thence to the study of the elastic equilibrium of rigid arches, Mr. Bell sought to substitute graphic methods for the long calculations which the establishment of the smallest project involved. The fundamental idea of the new method seemed to be the following: "The bending moment in a given point of the mean fibre may be obtained by multiplying the corresponding thrust by the distance of the point under consideration to the tangent to the curve of pressures;" a remark which gave a simple expression for the bending moments, especially if the exterior forces were vertical, as was shown by the Author.

The calculations contained in pages 68-71 included the formulæ known of the bending of curved structures freed from the terms due to the variation of the lengths of various successive arches. Here he begged to submit a slight criticism: Mr. Bell had arrived, p. 71, at the equation

$$h = \frac{1}{a\,\mathrm{I}} \Sigma \Sigma \mathrm{M} \triangle s \cdot \triangle y \quad . \quad . \quad . \quad (4)$$

to express the horizontal displacement of the deformed arch. The sum Σ ought to be extended from one of the extremities of the structure to the point of which the displacement was sought. To effect this double summation, Mr. Bell first sought $\Sigma \mathrm{M} \Delta y$, and made this expression equal to $\mathrm{M} y$, thus making the summation from the factor Δy only. This process seemed to him a little arbitrary. The summation indicated represented veritable integrals; now it was seldom that $\int \mathrm{M} \, d y = \mathrm{M} y$, but rather $\int \mathrm{M} \, d y = \mathrm{M} y - \int y \, d \mathrm{M}$.

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[1] *Vide* "Comptes Rendus de l'Académie des Sciences," tome lxx., pp. 229 and 281. "Sur une détermination rationelle, par approximation, de la poussée qu'exercent des terres dépourvues de cohésion, contre un mur ayant une inclinaison quelconque; par M. de Saint-Venant."

"Nouvelle théorie de la poussée des terres et de la stabilité des murs de revêtement," par J. Curie. (Paris, 1870.)

The substitution of $\mathrm{M} y$ for $\Sigma \mathrm{M} \Delta y$ was only rigorous if M were constant, which was far from being true in the majority of cases. The equation (6) was, therefore, not quite exact. Without insisting on this observation, of which he, perhaps, exaggerated the practical importance, he would acknowledge the very elegant manner in which the Author of the Paper drew up the formulæ of the relations which should subsist between the curve of pressures and the mean fibre. If, to satisfy these conditions, trials were often necessary, these trials seemed to him neither long nor difficult, especially in the particular cases of vertical loads uniformly spread, which were often found in structures. The numerous applications contained in Mr. Bell's Paper; his researches on the effect of moveable loads; his drawings of the greatest bending moments in the most ordinary cases; the three remarkable examples which he had developed, on the subject of lock gates, of elliptical caissons for tubular foundations, and of curved roofs under the influence of a violent wind, showed that his method could be adapted to the solution of the most varied problems. He should be surprised if it were not appreciated by engineers. He would state, in conclusion, that having occasionally had an opportunity of perusing the Reports of the Proceedings of the Institution, he could bear testimony to the care with which the subjects under discussion were studied, and to the impartiality of those discussions.

Professor J. Clerk Maxwell observed, through the Secretary, that if the Author of the Paper could prove that his method of measuring the strains on comparatively small portions, as 50 inches, of an iron structure was practicable, it would be a most valuable means of testing the accuracy of engineering calculations; and a careful examination of the marks before and after the erection, and again a year or two afterwards, would enable an opinion to be formed, as to the security of the structure itself, and as to the behaviour of iron under long-continued strains. Experiments were confined so exclusively to longitudinal stress, that instances of yielding to different kinds of combined stress, such as occurred in structures, must be very useful. For example, there was no evidence to show how the value of the greatest safe vertical pressure or tension would be modified if one, or two, horizontal pressures or tensions coexisted with it. Probably two horizontal pressures would increase the power of supporting a vertical pressure. A thorough discussion of the experiments of M. Tresca on lead might give some information as to that material, which, however, was not much used by Engineers. Nevertheless, a perusal of Tresca's "Sur l'écoulement des corps solides"[1] might be interesting to practical men, as it bore on the theory of punching and wire-drawing.

Mr. L. E. Fletcher observed, through the Secretary, in reference to the remarks in the Paper as to the effect of departures from the truly circular shape upon the strength of cylindrical boilers, that the Manchester Steam Users' Association had by no means been insensible to the importance of this subject, although they had not had any direct guide as to the precise value of given departures. It was the rule for their inspectors to gauge the furnace tubes of internally fired boilers, both horizontally and vertically, and to report minutely how far they varied from the true circle. This was done on every "entire" examination. They had long since impressed on steam users, when laying down new boilers, the importance of having the furnace tubes perfectly circular, and, with this view, had dispensed with longitudinal seams of rivets almost entirely, making each ring of plate in the furnace tube of one length circumferentially, and welding it at the longitudinal joint. In this way they avoided the overlap of the riveted joint, and were able to maintain a truly circular form.

No doubt many flues had collapsed under pressure, and thus given rise to explosions, in consequence of being out of the true circle; but this want of truth, as mentioned in the Paper, was difficult to ascertain after the collapse had taken place. In the external shells of boilers, departures from the true circular form inducing transverse strains, tended to beget grooving, from which many explosions of locomotive boilers had arisen, such as the one that occurred at Rugby in the year 1861, on the London and North Western Railway, through the bursting of the boiler of the engine attached to the Irish limited mail train.

To prevent the occurrence of these transverse strains they had recommended the introduction of double butt strips, one inside and one outside, so that the line of strain should run through the centre of the plate.[1]

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[1] *Vide* "Mémoire sur l'écoulement des corps solides soumis à des fortes pressions. Par H. Tresca. Comptes rendus hebdomadaires des Séances de l'Académie des Sciences, 1864." Tome lix., p. 754 *et seq.*

Professor **Fleeming Jenkin** said, the subject of stresses upon rigid arches was one to which he had paid some attention, believing as he did that for large spans the form was the most economical that could be adopted.

He had published in the "Transactions of the Royal Scottish Society of Arts" an investigation upon the stresses which would come upon a framed rib—not the common rib, shaped like part of a ring of nearly equal depth, but a curved lower flange or boom framed to a straight, or nearly straight, upper flange or boom. When the framing consisted of a set of triangles, this framed arch was an ordinary stiff frame, in which no part could in itself be strained. He believed the results given by Mr. Bell's method were correct, and identical with those obtained in the special case of an articulated frame by another method, due to Professor Clerk Maxwell. He thought one addition should be made to the Paper. It was quite clear the form of this curve of equilibrium depended upon the cross section of the rib, whenever that cross section was not uniform. Now, the point of real interest to Engineers was to get the most economical form of rib. They should not start with a preconceived notion that they were going to make this rib of uniform section throughout, and then be satisfied with finding out the stress from that assumption. If one part had a stress of 4 or 5 tons, and another of only 2 or 3 tons, the next thing was to lighten the rib at the place where the small section came. Therefore Mr. Bell's system of calculation, though simple and beautiful, was, nevertheless, for practical purposes, incomplete. It would be necessary by the same method of trial and error, after altering the section of the rib, to find the new curve of equilibrium, and from this new curve again to alter the section. This process would have to be repeated until it gave sensibly uniform stresses on all parts of the rib.

Now, when that was done, it would be found that, for bridges of large span, in which the permanent load bore a large proportion to the passing load, the inverted arch or suspension bridge, with considerable depth between the upper and lower members, came to be the most economical form of structure. The distribution of metal was very simple. Fig. 1 showed this distribution for the frame before alluded to; the breadth of each member as drawn being proportional to the cross section which it ought to have. It was clear, inasmuch as the arch had to resist transverse strains, there would be considerable advantage in making it stiff, and to do that it must be as deep as possible, for the same reason that a girder was made deep. It was desirable that the upper portion of the rib should be as far as possible from the lower curved one at the crown C; and, to take advantage of the full depth at the haunch D, the two portions A B and D C D should be connected by a simple form of trussing, or they might be joined with plates of wrought iron, as was done in the plates of a girder, and then the curve of equilibrium could be found by the means indicated by Mr. Bell and others. When this curve had been ascertained upon the supposition of a certain cross section for each member, each of those members should be proportioned to the strain that came upon them with the new cross section, the new curve of equilibrium should be found, and the cross section again slightly altered if necessary. It would then be discovered that the greater portion of the strain towards the centre went through the upper flange of the arch, and came down to the bottom flange at the springing. It was easy, by successive trials, to arrive at a curve of equilibrium, giving equal stress on every portion of the arch. That gave the most economical structure obtainable; and, for large spans, the amount of metal then required for an arch of this kind would be considerably less than for a girder, even of the same depth, that was to say of a depth equal to the full rise of the arch.

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[1] *Vide* Report of the Chief Engineer to Executive Committee of the Association for the prevention of Steam Boiler Explosions, November, 1862; May and June, 1864; January, February, and July, 1869; and December, 1871.

Fig. 1.

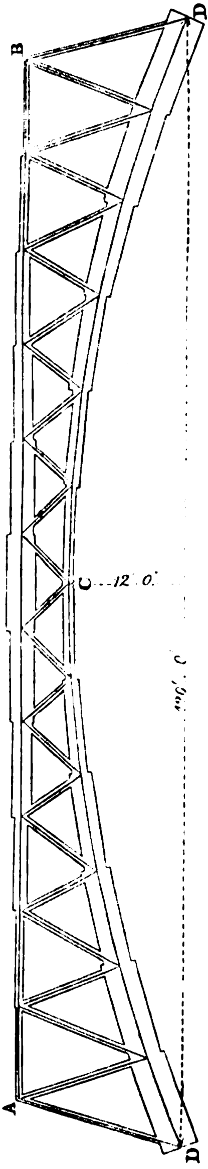


Diagram showing approximately the proper distribution of Material in a Framed Arch with uniform load.

Moreover, the arch had this advantage over the girder, that the long struts at the points of support, which in a girder would be necessarily much strained, were in an arch slightly strained, almost all the thrust being taken by the first member of the lower flange at the springing. The rigid arch, therefore, was not merely a construction of mathematical interest, but one of practical importance to the Engineer, as affording the best means of bridging over large openings. Mr. Bell had not proposed to treat of that portion of the subject; he had not gone into the question of the relative economy of girders and arches; but he had given a method of determining the curve of equilibrium, supposing that Engineers would apply it in the way he had endeavoured to indicate: yet it was interesting to show what was the result of the application of these methods of determining the curve of equilibrium.

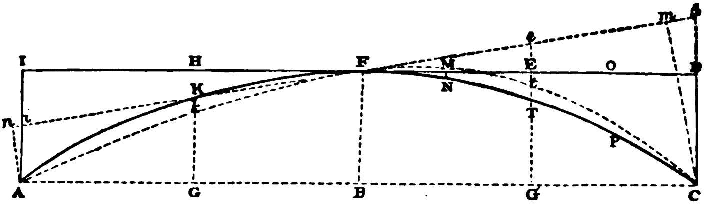
Mr. G. H. Phipps observed, through the Secretary, in reference to the Pont-y-tu-Prydd, that, in his opinion, so long as the upper boundary of the backing presented a line inclined to the horizon, and was also sustained at the end, as it frequently was, by a vertical wall, the usual manner of regarding its action, vertically, was more consonant with the nature of the material than the other manner suggested by the Author.

As regarded the important question of the true position in any arch of the curve of equilibrium to any load, it was frequently a matter of great convenience in calculations to be in possession of several methods of doing the same thing, as sometimes one, and sometimes the other, would afford special facilities, according to the circumstances of the case. He would therefore describe a method of obtaining the curve of equilibrium, which he had used for seven or eight years, and which he thought was simpler than that proposed by the Author. He was informed it had been described by Professor W. J. M. Rankine. This method consisted in obtaining the thrust of the arch, tangentially to the curve of equilibrium at the crown, then in conceiving the arch separated into two by cutting it through the crown, and that each half, instead of being retained in its position by the pressure against its neighbour, was so retained by a tensile force equal to the above pressure.

The tension would then be equal to the moment of the weight of each half arch taken into the horizontal distance of its centre of gravity from the point upon the abutment where it rested, divided by the distance from the same point, measured at right angles to the line of tension above referred to.

Thus, in Fig. 2, where all the full lines referred to an arch equally loaded, and the dotted lines to an arch only loaded

Fig. 2.



over one half of its span, the moments of the two half arches about the springing points A and C would be in each case equal to W, the weight of the half arch, into the distances A G, G' C, of the centre of gravity of each half arch from the springing point. When these weights were equal, the line of thrust, I F D, at the crown would be horizontal, and when replaced as described, by tension, the amount of tension would be equal to the above moments divided by A I, or C D. To find points in the curve of equilibrium, somewhere in the vertical lines M N and O P, it was only required to ascertain the weights of the portions of the arch and its loading which lay between the crown F and the points M and O, together with the distances of their centres of gravity from the same points, and to find the moments due to those weights and distances, dividing which by the tensions previously obtained on F I = F D would give the ordinates M N and O P; and in this manner any number of points in the curve of equilibrium might be readily found.

Taking, now, the case of unequal loading on the two half arches, calculating, as before, their separate moments about the springing A and C, and dividing by the distances A *n*, and C *m* (which were to one another in the same proportion as the weights of the respective half arches to which they belonged), the result was the tension upon the inclined line *i* F *d*.

The inclination of *i* F *d* was obtained by erecting the two perpendicular lines A *i* and C *d* on the springing points, each line being proportional to the weight of the half arch nearest to it, and their actual length such that B F (the versed sine of the arch) should be the mean between the two; thus, if the respective weights were as 1 and 3, and the central height 20 feet, A *i* would be 10 feet, and C *d* 30 feet. He had already observed, that the tension on *i* F *d* was equal to the moments of the half arches divided by A *n* and C *m*; but when the object was simply to determine the curve of equilibrium, it was most convenient to make use of the horizontal component only of the tensile force, and to consider it as acting upon the longer leverages A *i* and C *d*, the moments being in both cases the same. When this reduced tension was used, the vertical ordinates reaching from the inclined line of tension down to the curve of equilibrium, as *a l*, *h k*, &c., would be found precisely in the same manner as for the fully-loaded arch.

It might be here remarked, as a useful generalization, that when the half arches were considered to be each uniformly, though differently loaded, the vertical change of position from the curve of equilibrium, A K F L C, of the fully loaded condition, to the other curve of equilibrium, A *k* F *l* C, was K *k* and L *l*, each equal to $\frac{1}{4}$ the heights D *d* and A *i*.

Thus, in an arch of 200 feet span and 20 feet rise, when the weight of the unloaded side was to the loaded side as 1 to 3,

$$\mathrm{D}d = \mathrm{A}i = 10 \text{ feet, and } \mathrm{L}l = \mathrm{K}k = \frac{10}{4} = 2\cdot5 \text{ feet.}$$

It might be further added, that the use of the horizontal component of the tension on the line *i d*, instead of the actual force, afforded great facility for ascertaining the bending moment at any point of the arch when the line of the centre of gravity of its sections did not accord with the line of the curve of equilibrium, as at K and L; for instead of the necessity of computing the actual strain at those points, which was troublesome, and differed at every point, and of taking that strain into the length of a line nearly normal to the two curves, it was only necessary to take the constant horizontal component of the strain, above described, into the vertical line between the two curves, as K *k* and L *l*, which was a much simpler process.

This showed how a curve of equilibrium might be drawn to any kind of the loading of an arch, passing through the two springing points and the centre at the crown; but, as he had explained elsewhere,[1] there might be an infinite number of such curves, differing in altitude but all appropriate to the loading, the question was, how to select the right one. Now he thought the principle on which he made the selection of the true curve was identical with that used by the Author, consisting in both cases of a valuation or assessment of the angular motion around any, and every, point in the neutral axis of the arch, wherever the curves of the neutral axis and of equilibrium did not coincide.

With regard to the low coefficient of pressure hitherto generally adopted on iron arched structures—in those for railway purposes, the proportion of the fixed weight to the rolling load generally was small, perhaps in a bridge of 200 feet span and 20 feet rise about 1 to 2. This great disparity, when the bridge was loaded over one half its span only, would give rise to a change of position between the neutral axis and the curve of equilibrium at the quarter span of 2 feet 6 inches; a quantity which, upon the usual I-formed section of such ribs, would considerably more than double the initial pressure per square inch acting tangentially to the arch, and therefore, if this latter were taken at 2 tons to the square inch, it would be increased to beyond 4 tons by the angular motion. In proportion, therefore, as the angular motion could be reduced, the direct pressure might be increased; and this it was now proposed to show might be done to such an extent as to admit of the direct pressure, in the fully loaded condition of the arch, being put at, for wrought iron, 3½ tons on the inch; a pressure which would nearly compare with that upon the upper or compressed booms of ordinary girders; while, if the material were cast iron, 4 tons on the inch might be safely applied.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxi., p. 134.

Fig. 3.

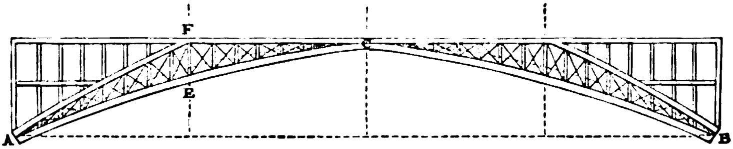

Fig. 3 represented a design for an arch of 200 feet span and 20 feet rise, in which the rib, instead of being solid as usually constructed, was composed of open work diagonally trussed. The total depth of the rib at the quarter span was 11 feet 6 inches, the depth from the lower side to the neutral axis was 4 feet 6 inches, and the upper side reached quite to the level of the under side of the cross girders for carrying the platform and railway. The form of the arch rib was obtained by first drawing a curve of equilibrium to the fully loaded condition, through the points A, C, and B, which curve was also to be the neutral axis of the rib, and then drawing the curve of the intrados, not equi-distant everywhere from the former curve, but considerably farther from it at the point E than at A and C; namely, 4 feet 6 inches at the former point, and 2 feet only at the two latter points, thus giving a somewhat pointed contour to the arch at the crown. As a consequence of the member of the arch at F being so much farther from the neutral axis than that at E, the areas of the transverse sections of those parts must be in the inverse proportion of their distances from the neutral axis. With the above proportions he had calculated the pressures upon an imaginary arch, for a railway bridge of 200 feet span and 20 feet rise, having a fixed load from its own weight, the platform, rails, &c., of ½ ton, and the train load 1 ton, both to the foot run—

	Tons.
In the fully loaded condition the total compression on one rib at the crown would be.	187·5
Ditto ditto at the quarter span	191·25
When loaded over one half of the arch only, at the quarter span	137·11

	Square Inches.
Total sectional area of the rib at the quarter span, if of wrought iron	55½
Ditto ditto cast iron .	47¼

In the case of wrought iron, the strains would be—

	Tons on the Inch.
Due to direct pressure	2·47
Due to angular motion	1·53
Total	4·00

And for cast iron—

Due to direct pressure	2·9
Due to angular motion	1·8
Total	4·7

The above favourable result was obtained by making the moment of inertia of a section of the arch very great, without increasing the sectional area at the point E, where it was most subject to increase of pressure from the altered position of the curve of equilibrium consequent upon irregular loading.

On this question, however, of increasing the moment of inertia, the depth of the section must be borne in mind, as, with equal angular movement, the deeper section was most injuriously acted upon. A general rule for this might be given as follows, in which the bending moment was assumed constant. The actual movement of any fibre, due to angular motion, around the neutral axis, was as its distance from that axis divided by the moment of inertia of the section.

The above considerations relative to the economising of material in arched structures naturally led to the examination of some of the methods for giving stiffness to arches which had been at different times proposed. One of these, by Mr. Heppel, consisted in first making the arch itself very thin and flexible, and then obtaining the requisite stiffness by means of continuous longitudinal girders, attached all along to the arch, and bolted down to the abutments. But he did not think this arrangement would turn out economical. According to Mr. Heppel,[1] "in an arch of the dimensions of the Victoria bridge [over the Thames] he calculated that 50 inches of section would be sufficient to support mere compression, whereas in that bridge there were 80 inches of section, and that the stiffening girder would require only what was equivalent to an average section of about 50 inches." This would lead to the following contrast:—

	Square Inches.
The sectional area of the arch rib in the Victoria bridge was	80
And the sectional area of the horizontal member above	50
Together	130

Whereas, according to Mr. Heppel's proposal—

The sectional area of the arch rib might be	50
„ „ girder	50
Total	100

He thought, however, the case should be differently stated, as in the actual bridge the direct pressure was 3 tons to the inch, where, on Mr. Heppel's system, more than 4 tons for wrought iron ought not to be admitted. This would bring

	Square Inches.
The sectional area of the arch rib on Mr. Heppel's system to	60
And the sectional area of the girder as before	50
Total	110

On the plan Mr. Phipps proposed—

The arch would have	68·5
Add for proportion of railway bearer, say	23
Total	91·5

From the above estimate it would appear that Mr. Heppel's system would not prove as economical as his own; and therefore, bearing in mind also that the former consisted of diverse parts, while the latter had but few, he thought it fair to decide against the girder system. In his opinion, the most useful, he might almost say indispensable, application of Mr. Heppel's system was in the important matter of rendering suspension-bridges of large span sufficiently rigid for railway purposes.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxi., p. 140.

Mr. **Wilfrid Airy** thought the Author had been unfortunate in the use of the word "rigid," as applied to iron arches. The entire investigation of such arches depended upon their being elastic and allowed to change their shape, which they could not do if rigid. It seemed difficult to find a single good word to express what was wanted. He had himself used the word "continuous" to define an arch in one piece, but it was not a good word; and he considered the phrase "elastic arches" would best meet the circumstances of the case, because continuous arches were the only ones that could be truly called elastic.

With respect to the three cases of arches investigated by the Author—the voussoir arch, the iron arch between abutments, and the iron arch with the ends rigidly fixed—he thought the last seldom occurred in practice. The only example he could imagine was that of a series of arches in a row, where the adjacent ends were rivetted together. Perhaps, however, the arched roof of the St. Pancras station was a case in point. A single arch with its ends imbedded in masonry abutments was scarcely a practical illustration; for, in the first place, it would be difficult to secure the requisite conditions of rigid fastening; and in the next place, if those conditions were secured, they would be attended with danger to the masonry of the abutment from the straining of the arch.

He considered the Author's plan of exhibiting strains by geometrical construction was very elegant, but he did not think labour was saved by it, because the accuracy of the approximate curve depended entirely upon the number of points that were calculated. In this respect it differed from geometrical constructions, which actually saved labour. He might instance the case of an ellipse: it was of course possible to construct an ellipse by calculating the ordinates from the equation and plotting them down; but the ellipse could be much more easily described by means of a pair of compasses and a parallel ruler; and in this case the geometrical method absolutely saved labour.

The Author's investigation of the strains produced by a small alteration of the span of an arch was an important matter, not so much on account of its magnitude as on account of the difficulty of arriving at a result by short cuts, or rough and ready methods. He had carefully read the Author's investigation, and, in his opinion, the Author had over-stated the results in the examples taken; for he had stated that, in the case of the example then considered, "When the shortening of the span by the compressive force f is $\frac{1}{2}$ inch, then the additional stress at the outer surface of the rib at the crown, caused by the virtual lengthening of the span from compression, will be $\frac{3}{4}$ ton per square inch." Now, he had himself investigated this problem very carefully, and the result which he had arrived at was only $\frac{1}{4}$ ton per square inch, instead of $\frac{3}{4}$ ton as obtained by the Author. He believed this difference was caused entirely by the rough methods of approximation employed by the Author in this investigation, some of which he considered to be inadmissible. He would not have advanced such an opinion without careful examination, and he would submit his own investigation, that it might have the benefit of the Author's criticism.[1]

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[1] INVESTIGATION of the STRAINS produced in an IRON ARCH by CONTRACTION OR EXPANSION of the METAL.

The investigation would be the same either for contraction or expansion, and it will be convenient to consider the case of an iron arch under expansion due to increase of temperature. The strains produced by the expansion may be considered apart from any other strains produced by loads, &c., and the effect on the arch will be the same in whatever position the arch is placed. Let, therefore, the iron rib be laid flat on the ground: it is then without strain, and it would remain without strain under expansion if it be free to elongate in all its parts without coercion. Under these circumstances the shape of the rib would be accurately preserved, and a circular rib would always remain a circular rib, but of slightly varying radius. If, however, the ends of the arch be prevented from spreading out under expansion (by wedging up against fixed abutments), the shape of the rib is necessarily altered or distorted. The object of the present investigation is to determine the amount of strain which the metal of the arch sustains in consequence of this distortion.

The only force acting upon the arch is the thrust of the abutment, which prevents the feet of the arch from spreading out, and so distorts the arch. If this force were known, the strain at any part of the arch could be obtained at once, and the immediate object is therefore to determine this force. This may be done as follows:

First. Calculate what the spread of the foot of the arch would be, due to the strains caused by an assumed thrust force (h) at the abutment.

Secondly. Determine from geometrical considerations (for a given amount of expansion), what the actual displacement of the foot of the arch is, by the coercion of the abutment.

Thirdly. Equate the two expressions so obtained, and from the resulting equation determine the value of (h).

Proceeding then to the first * of these operations:

Let A C B (Fig. 4) be an arch wedged up as described; (R) the radius, and (α) the half-angle of the arch. Let P be a point on the arch defined by the angle (θ), and draw A Q, P Q the co-ordinates of P. Also, let (h), (h) be the thrust forces of the abutments.

* This part of the investigation is extracted from the Treatise on "Iron Arches," by Mr. Airy, and referred to in Mr. Bell's Paper.

Mr. W. H. Bidder observed that there was a confusion of terms in the Paper, with respect to the centre of gravity of the cross

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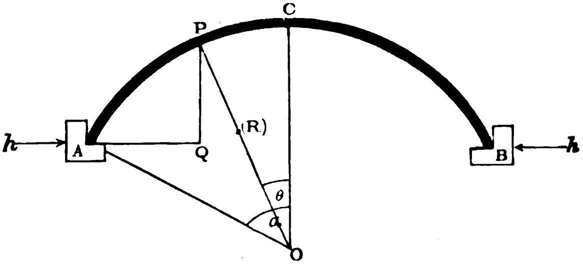
The bending moment at P is $h \times PQ = h \times R\,(\cos\theta - \cos\alpha)$, and since the curvature at P is proportional to the bending moment at that point, the reciprocal of the radius of the circle into which the fibres of the iron at P are bent by the bending moment is $E\,.\,R\,.\,h\,.\,(\cos\theta - \cos\alpha)$; where (E) is a constant depending on the section of the rib and the elasticity of the metal.

Fig. 4.



If then two points are taken on the arch, whose curved distances from the crown of the arch are $R\,.\,\theta$ and $R\,.\,(\theta + \delta\,\theta)$, the fibres at the second point are bent downwards with respect to their original direction in regard to those of the first by the angle $E\,.\,R^2\,.\,\delta\,\theta\,.\,h\,.\,(\cos\theta - \cos\alpha)$.

Join A and P by a straight line; then the bending on the element $R\,.\,\delta\,\theta$. will throw the point A through the space $A P \times E R^2\,.\,\delta\,\theta\,.\,h\,.(\cos\theta - \cos\alpha)$, in the direction perpendicular to A P, and the resolved part of this inwards is $A P \times E R^2\,.\,\delta\,\theta\,.\,h\,(\cos\theta - \cos\alpha) \times \frac{P Q}{P A} = P Q \times E\,.\,R^2\,.\,\delta\,\theta\,.\,h\,(\cos\theta - \cos\alpha) = E\,.\,R^3\,.\,\delta\,\theta\,.\,h\,(\cos\theta - \cos\alpha)^2$.

This must be integrated from $\theta = o$ to $\theta = \alpha$, to obtain the entire inwards spread of A, and it will be found that the result is:

Total spread of foot due to strains caused by a thrust force (*h*) at the abutment =

$$E\,.\,R^3\,.\,h\,.\,\left\{-\tfrac{3}{2}\sin\alpha\cos\alpha + \alpha\left(\tfrac{1}{2}\sin^2\alpha + \tfrac{3}{2}\cos^2\alpha\right)\right\}.$$

The next operation is to determine, from geometrical considerations, what the actual displacement of the foot of the arch is:

Let A B (Fig. 5) be the arched rib unexpanded, and O the centre. Join O A, O B, and produce them to C and D respectively. Then C D is the expanded arch with the ends free, for a given amount of expansion. Draw C E parallel to A B, and A E perpendicular to A B. Then C E is the extent to which the arch is prevented from spreading at each end by the abutments. Let R be the radius of the arch, and (α) the half-angle of the arch.

Then $C E = A C\,.\sin\alpha$.

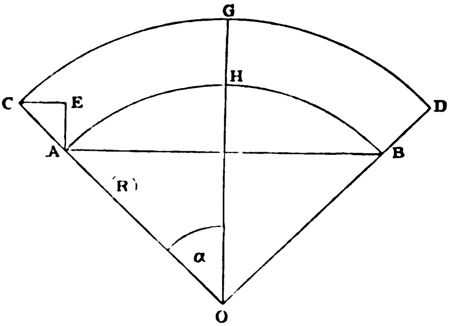
But $\frac{O A + A C}{O A} = \frac{C G}{A H} = \frac{A H + \mu}{A H}$, where μ = the absolute amount of expansion on the half-arch.

Or. $\frac{A C}{O A} = \frac{\mu}{A H}$ and $A C = \frac{O A}{A H}\,.\,\mu = \frac{\mu}{\alpha}$.

sections, for this was designated by some, including the Author, as the neutral line, and by others as being both the neutral line and the line of mean fibre.

Therefore O E $= \frac{\sin \alpha}{\alpha} . \mu$, or the actual displacement of the foot of the arch is $\frac{\sin \alpha}{\alpha} . \mu$.

Fig. 5.



Lastly, equating the results obtained by the preceding operations, we have :

$$E . R^3 . h \left\{ - \tfrac{3}{2} \sin \alpha \cos \alpha + \alpha \left(\tfrac{1}{2} \sin^2 \alpha + \tfrac{3}{2} \cos^2 \alpha \right) \right\} = \frac{\sin \alpha}{\alpha} . \mu;$$

$$\text{or, } h = \frac{\mu}{E . R^3} . \frac{1}{- \tfrac{3}{2} \sin \alpha \cos \alpha + \alpha \left(\tfrac{1}{2} \sin^2 \alpha + \tfrac{3}{2} \cos^2 \alpha \right)} . \frac{\sin \alpha}{\alpha}.$$

Let now the foregoing principles be applied to the example selected by Mr. Bell, as follows:

An elastic arch of 200 feet span, and 20 feet rise, is compressed by a thrust force of 4 tons per square inch: the depth of the rib is 4 feet, and the section box-shaped. What is the strain on the metal caused by the compression of the arch and consequent change of shape ?

The radius (R) will be found to be 260 feet, and the angle of the half-arch (α) = 22° 37′, the circular measure of which is ·396. Therefore the length of the half-arch is 260 × ·396 = 103 feet.

A thrust of 4 tons per square inch will shorten the half-arch by $\frac{4}{10,000} = \frac{4}{10,000} \times 103 = \cdot 0412$ feet = ½ inch. Consequently the metal of the arch will sustain a strain due to a forcible outward pull on the feet of the arch to the extent of $\frac{1}{2} \times \frac{\sin \alpha}{\alpha}$ inches $= \frac{1}{2} \times \frac{\cdot 385}{\cdot 396} = \cdot 486$ inch. Also it will be found that the expression $- \frac{3}{2} \sin \alpha \cos \alpha + \alpha \left(\frac{1}{2} \sin^2 \alpha + \frac{3}{2} \cos^2 \alpha \right)$, when for ($\alpha$) is substituted its value, viz., 22° 37′, becomes = ·005. Therefore the equation at the end of the last paragraph for the determination of (h) becomes,

$$h = \frac{1}{E . R^3} \times \frac{\cdot 486}{\cdot 005};$$

$$\text{or, } h = \frac{1}{E} . \frac{1}{(12 \times 260)^3} \times \frac{\cdot 486}{\cdot 005} = \frac{1}{E} . \frac{97 \cdot 2}{30,371,328,000}.$$

He desired to remove this confusion, and to show, in the first place, that this could not be the neutral line of the rib in any case; and, in the second place, that it might or might not be the line of mean fibre, so that this expression could not always be made use of. Three other expressions might have been employed, either of which would have caused no confusion. In the first place, this line was the centre of gravity of all the cross sections; in the second place, it was the line of normal stress; and, in the third place, it was the axis of rotation upon which all the angular motion took place; neither of which terms, if made use of, would have caused any confusion, although he was of opinion that the latter expression would be the best.

Before the neutral line could be determined, two of the three expressions, viz., the centre of gravity, and the amount of normal pressure at any point, must be determined; the neutral line could then be found, should such a line exist. The process of investigating the strains on rigid arches was comparatively new, or rather, had only recently been made public, although a method of ascertaining the curve of pressure due to the rolling load had been shown to him by Mr. Phipps, eight or ten years since. Mr. W. Wilson had exhibited a diagram of the strains on the ribs of the Victoria Bridge, Pimlico,[1] which, if correct, showed that no neutral line could be drawn in that case, for the entire mass was in compression, more or less. Subsequently, Dr. W. J. M. Rankine wrote an article "On the straining actions upon Arched Ribs,"[2] in

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As the section is box-shaped, a close approximation will be obtained to the true value of E by omitting the resisting moment of the web. In this case $E = \frac{2.e}{S.b^2} \cdot \frac{k}{\omega}$, where ($e$) is the proportionate extension caused by a weight (ω) on a sectional area (k), b = the depth of the rib, and S = the sectional area of the top of the rib. Now when $\omega = 1$ ton, and $k = 1$ square inch, $e = \frac{1}{10,000}$; and if it be assumed that $S = 1$ square inch, and there be put for (b) its value, viz., 48 inches, then

$$E = \frac{2}{10,000 \times (48)^2} = \frac{1}{11,520,000}.$$

$$\text{Therefore } h = 97 \cdot 2 \times \frac{11,520,000}{30,371,328,000} = \frac{97 \cdot 2}{2,626} = \cdot 037 \text{ ton,}$$

and the bending moment at the crown = ·037 × 240, and the resisting moment of the metal = t × 48 (t being the strain of the metal required). Consequently,

$$t \times 48 = \cdot 037 \times 240.$$
$$t = \cdot 185 \text{ ton per square inch.}$$

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvii., p. 66.

[2] *Vide* "The Engineer," vol. xxv., p. 2.

which he treated the subject as a new one, and gave a method of finding the curve of equilibrium for a static load, by assuming the rib to be two cantilevers springing from two walls, and of the depth at that point equal to the rise, and meeting at the centre, a method that had been employed by Mr. Phipps and himself for many years. Now Dr. Rankine, after a few preliminary remarks, and without giving any reason, commenced by saying, "Let A, B, C, D, be the neutral line (traversing the centres of all the cross sections) of a half-rib of any shape, &c.;" thus assuming it a case of necessity that there must be a neutral line, and that line in the centre of gravity of the sections. He further remarked, "To find the intensity of the tension (t) at the stretched edge of the cross section of greatest bending moment;" and here he gave a formula for finding this. But it would be observed that if the neutral line was in the centre of gravity of the section, the intensity of the tension would be identical with the intensity of the compression, which was impossible, because rupture would take place long before this could occur. Moreover, the angular motion produced by the bending moment would become parallel to the line of the centre of gravity of the rib, instead of being at right angles to it, or nearly so. M. Gaudard also described the line of the centre of gravity of the section as the line of mean fibre.[1] But, as he had before observed, this line might, or might not, be a line of mean fibre, according to circumstances which could be better explained by the following figures.

Fig. 6.

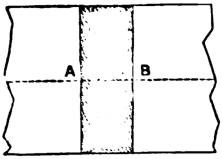


Fig. 7.

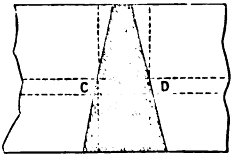
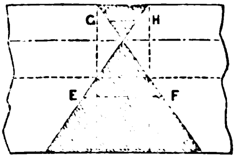


Fig. 8.



Let Fig. 6 be a cross section of a rib of uniform section, the curve of pressure coinciding with the centre of gravity of the section, and let A B represent the amount of pressure normal to the cross section, then the compression over the whole area of the section would be uniform throughout; but if the curve of pressure moved away from this line, say a little distance below the centre of gravity, such as C D, Fig. 7, angular motion would follow, the uniformity of compression would no longer exist, and the pressure would be increased in the lower fibres and diminished in the upper ones. The fibre at the centre of gravity of the section would be a mean fibre, and would remain so, until some portion of the rib came into tension, when there would occur two lines of mean fibre, as E F and G H, Fig. 8; the line E F representing the line of mean fibre of that portion of the rib in compression, and the line G H the mean fibre of the portion of the rib in tension, neither of which entered into the calculation; and it would be seen by this, that the line of mean fibre was no longer in the centre of gravity of the section, but had shifted its position towards the outer fibres of the cross section.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxi., pp. 76 and 83.

Again, M. Gaudard observed, "For the maximum of the stress R, the fibres must be considered as the farthest removed from the neutral axis."[1] This was really the case; but M. Gaudard had previously stated, "This applies always to a circular arch of uniform section, this section being also symmetrical relatively to the neutral axis, which occupies the middle of its height *h*."[2] These two observations did not agree; for in the former case the neutral line would be always further from one extreme edge of the section than from the other, unless the rib was on the point of rupture, when the neutral line would approach the centre of gravity of the section until rupture took place; while in the latter case the neutral line was assumed to be in the centre of gravity of the section, which, it had been observed, did not agree with the former. Moreover, M. Gaudard, as if to make it quite clear that the neutral axis coincided with the centre of gravity of the section, took the case of an existing timber arch formed of three ribs of timber, kept apart by blocks of wood, of which he gave a diagram; and further on remarked, "Let the section at the summit, drawn in Fig. 8, and whose area is = 0·0728, be tried. It is for convenience of execution that this somewhat irregular form has been adopted; it will, however, be remarked that the mass of matter is distributed symmetrically above and below the neutral axis, in order that this axis may occupy the middle of the height."[3] Thus M. Gaudard clearly defined the neutral axis to be in the centre of gravity of the section, and this without assigning any reason.

Mr. Phipps, in the discussion on the same Paper,[4] had fallen into a similar error to Dr. Rankine and M. Gaudard, by confusing the axis of rotation with the neutral line, for if the expression "axis of rotation" had been used instead of neutral line in the first instance, his remarks would have been correct.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxi., p. 106.

[2] *Vide* Ibid., p. 88. [3] *Vide* Ibid., p. 102. [4] *Vide* Ibid., p. 133.

The Author, also, appeared to have been similarly misled, for he said, "The rib is subject to general compression throughout its whole length." Now, although this was generally the case, and indeed was always the case when no neutral line could be drawn in a rib; yet it was obvious that, when a neutral line did occur, some portion of the rib, viz., that lying on one side of the neutral line, must be in tension. Besides, he made use of the expression "neutral axis" in many cases where the proper expression would have been "axis of rotation," as when, speaking of the St. Pancras roof, he definitely settled the neutral line to be in the centre of gravity of the section.

The proper course was to ascertain the neutral line, if any, and this was the object aimed at by the authorities he had alluded to, and to which all the formulæ given by them tended, though it would seem to have been unintentional on their part.

He considered the graphic methods given by the Author, for finding the curve of equilibrium and the pressure at any part along the curve, were so simple that they needed no further explanation; but this was not the case with the diagrams for ascertaining the cross strain upon the rib, due to the bending moments caused by the curve of pressure not coinciding with the centre of gravity of the cross sections. The formulæ given by the Author were almost the only ones of any use extant. No mathematical formulæ could be devised that would satisfy all cases, but repeated approximations must be made; for if the rib was assumed to be of the **I** form, with the flanges equal, and the curve of equilibrium coincided with the centre of gravity, then the axis of rotation would be midway between the flanges and the radius of gyration calculated from it, and the radii would be the same for either flange. But if the curve of equilibrium shifted from the centre of gravity, and fresh calculations were made, it would be found that the strains on the flanges were no longer equal, and to restore equilibrium one of the flanges must be diminished and the other increased. The axis of rotation would then no longer remain in the centre of the rib, but would shift nearer to the larger section, or to the centre of gravity of the new section, the axis of rotation being identical with the centre of gravity, and the radii of gyration would be altered in their lengths. To examine the strains due to the new figure, fresh calculations would be required, and the process would have to be repeated as long as the sections of the flanges were being altered. The formula given by the Author for this process was very simple, but any attempt to examine the strains by one calculation, when the curve of pressure approached one of the flanges, or passed outside it, would prove abortive.

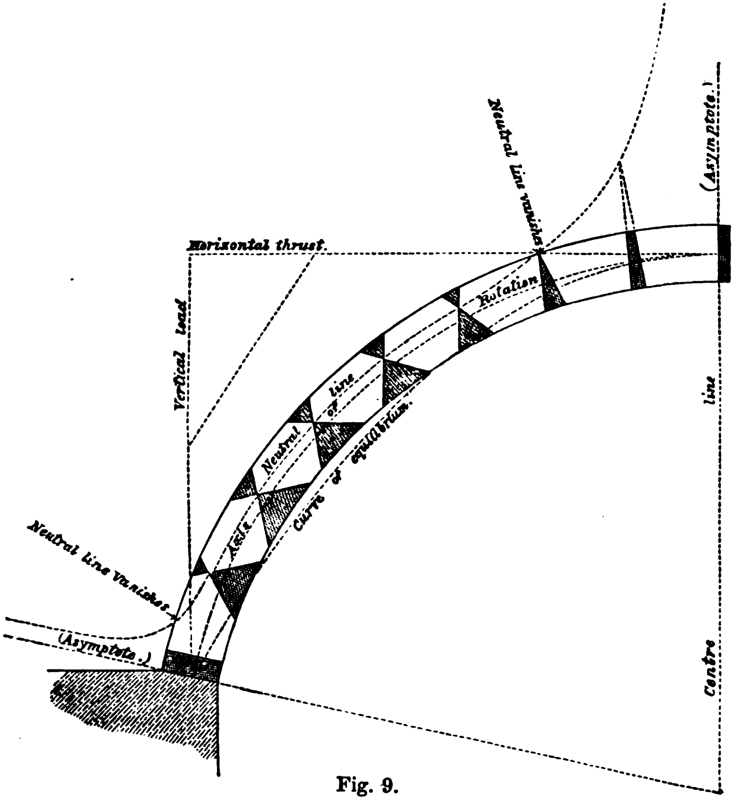
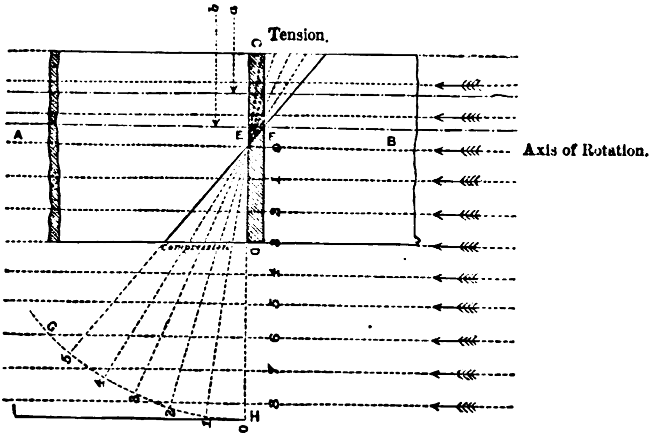

Neutral line vanishes
(Asymptote.)
Horizontal thrust.
Vertical load
Rotation
line
Neutral
of
Axis
Curve of equilibrium.
line
Neutral line vanishes
(Asymptote.)
Centre

Fig. 9.

Fig. 9 represented a half-elevation of a segmental rib of a rectangular section, whose centre of gravity was midway between the extreme edges. The rib was supposed to be without weight, and to be loaded with a uniform horizontal load; therefore the curve of pressure would be a parabola. If the normal stresses were calculated at various points along the curve, and then transferred to the line representing the centre of gravity of the cross sections of the rib, this line would become the "axis of rotation" for all the angular motion which took place on the cross sections, increasing the strain on the inside fibres, and diminishing it on those outside, and, in fact, bringing some portion of them into tension. The result was a neutral line, which was traced out on the rib by the apices of the triangles, where those representing the compression met those representing the tension when the angular motion was very great; but when the angular motion was so much reduced that only one triangle could be drawn, then the apex of this triangle would indicate where the neutral line vanished or left the rib; and although this line no longer remained a neutral line, its position could still be traced, by producing the lines representing the angular motion until they met, which would be points in the curve. The vertical line through the crown, and the line through the springing, being prolonged, represented asymptotes; and the points where these lines passed through the rib were the only points where the normal pressure remained parallel, because they were the only points in the rib where the curve of pressure coincided with the centre of gravity. Fig. 9 also showed how the neutral line was traced in a rib by the angular motion, should such a line exist. It would be seen that in a rib of rectangular form, if the curve of pressure deviated only $\frac{1}{6}$th of the depth of the rib from the axis of rotation, the angular motion would double the compression on the fibres on one side, and reduce it to nothing on the other; and that if the curve of pressure were moved beyond that, tension would commence, and the neutral line, separating the particles in tension from those in compression, could be drawn.

Fig. 10.



Note.—*a*, neutral line when load is at 2. *b*, ditto when load is at 5.

Let Fig. 10 represent a portion of a rib of rectangular form the centre of gravity being midway between the extreme edges If it were assumed that the load was placed in the centre the pressure would be equally distributed over the whole section, and this might be represented by the rectangle C D; the measure of the load being represented by the breadth of the rectangle, or by the line E F. This line would always remain constant with the same load, wherever it be placed; and if the weight be moved away from this line, angular motion would take place, from the strain being diminished on one side of the line, and increased on the other. If E represented the point at which the angular motion took place, the line A B would be the "axis of rotation." Then, if the breadth of the rib were supposed to be divided into six equal parts, such as 0, 1, 2, 3, and the weight be moved to 1, the strain at D would be doubled, and that at C would become nil; and if, again, the weight be moved to 2, the strain at D would be trebled, and the tension at C would be 1. In moving the load from 1 to 2 a neutral line would be introduced, whose position, when the weight had reached the line 2, would be indicated by the rotating line 2, where it intersected the upper line of the rectangle; and it would be seen that as the weight was passed towards the edge, or beyond it, and as the rotating lines were produced, the neutral line would approach the centre of gravity of the section. Now, if dotted lines representing the various portions of the load, and of the same units of distance, were drawn outside the rib; and if the line C D were prolonged to H, and a curve, G H, were drawn, of which the centre was at E, and the radiating line passing through the point E touched the rectangle at C, and distances equal to 0, 1, 2, were plotted along the curved line G H, these points would be radiating points corresponding to the various positions of the load, 0, 1, 2, &c. If the distances G, 1, 2, &c., had been drawn on a vertical line, as I H, this would not have been strictly correct. The investigation showed that the angular motion varied as the weight into the distance of the line of application of the force from the centre of gravity—a fact proved by experiment.[1]

The Paper was a most valuable one; but he regretted that the term "axis of rotation" had not been used by the Author in place of "neutral axis," for the line traversing the centre of gravity of all the cross sections, as the latter had an ambiguous meaning.

Mr. J. M. Heppel observed that the method described by the Author had been treated as a clumsy kind of expedient, but those who had studied the works of Leslie and Dr. Robison, or who had had the advantage of being acquainted with the late Mr. Charles Heard Wild, and knew his aptitude in the application of geometry to the investigation of these questions, would have no reason to undervalue it. He thought this communication valuable, as more fully developing the capabilities of graphic investigation than any other that had been brought before the Institution. But however much he admired the acumen with which the Author had investigated the case of rigid or continuous structures, he was of opinion that the problem was still worth the attention of engineers.

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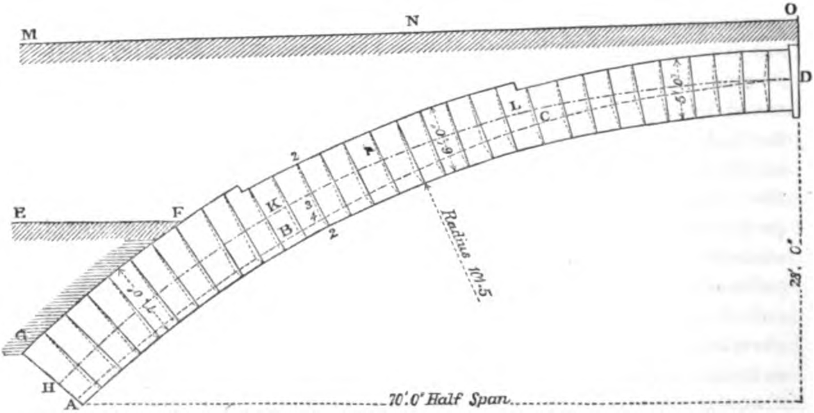
[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiv., p. 446.

He did not know whether there might be any objection in detail to urge against Mr. Bell's special conclusions as to continuous beams, but he had shown that the graphic method was a very powerful and effectual one to apply to the investigation of this subject; and though he was disposed to agree with Mr. Airy, that it was doubtful whether any great amount of labour would be saved by the application of the graphic instead of the analytical method, still he thought the two mutually strengthened one another. The one was a powerful check upon the other, and the graphic method offered an advantage to the practised eye. It presented a perfect picture, at one glance, of what the mechanical state of the structure was. Mr. Bell's suggestion for drawing the ordinates which represented the stresses over the piers by what he called a tentative process, must have been made with a view of showing how perfectly independent the graphic system was of any extraneous assistance; for he thought the equation known as the theorem of the three moments was brought to a state which did not give much difficulty in any case in at once deducing the strains over the piers; and these established, the method proposed by Mr. Bell was probably a rapid and convenient means of following out the whole subject to its consequences. The choice perhaps depended more on the individual, whether he had greater aptitude for applying one system or the other; but he thought there could not be a doubt that a Paper which, like this, proved so clearly the unquestionable power of the graphic method as one of effectual investigation (it had long been recognised as a means of teaching or demonstrating) was one which would be appreciated highly.

Major J. Browne, R.E., said he considered all Engineers must be indebted to the Author for this able Paper, which would now allow of stresses on arches being determined without the use of the complicated mathematical formulæ hitherto required. The system was identical, in principle, with the methods proposed by Rankine, Gaudard, and others: but, by using the graphic method, it was quite independent of the algebraic equation to the curve of the neutral axis; and at once did away with all the difficulties of integration, which rendered the use of the analytical method practically inapplicable to anything but a parabolic rib. The case of the elliptical caisson, for instance, so neatly treated by graphic methods, was quite unmanageable by mathematical analysis.

With respect to the curve of pressures, or of equilibrium, in a masonry arch, he had seen a case in which a brick arch of 140 feet span, with a rise of 28 feet, of the form and dimensions shown in Fig. 11, actually adapted itself to the theoretical curve of equilibrium suited to its distribution of weights; and with sufficient distinctness to allow it to be chalked down on the face of the arch. The bricks employed were only 2¼ inches thick, the joints running through from the intrados to the extrados, and drawn perfectly straight, normally to the curve. On the centreing being struck, which was done two days after keying in, it was noticed that the joints, though previously straight, had all become more or less curved, or crooked. A straight-edge being applied to them at every 4 or 5 feet, the points were marked where the bent joints most diverged from the straight-edge. A chalk line was then drawn through the points so obtained, on the face of the arch, and a curve, A, B, C, D, Fig. 11, was described, which was subsequently found to correspond almost exactly with the theoretical curve of equilibrium suited to the weight of the arch, and to the small amount of backing, E, F, G, built up at the haunches when the centreing was struck. The curve H, K, L, D was the curve of equilibrium due to the complete backing M, N, O, also supposed to pass through D, the

Fig. 11.



centre point of the crown. The joint 2, 2, being originally normal to the curve of the intrados, assumed after easing of the centre the shape 2, 3, 4, 2; the point 4 being the farthest from the line 2, 2, and determining the curve A, B, C, D. In this case the joints, being very thin and flexible, seemed to have yielded, and bent at the centres of greatest pressure, and thus to have defined for themselves the course of the curve of equilibrium through the body of the arch. As to the oblique, or normal action of puddle backing on the arch, there seemed reason to suppose that backing put on before the striking of the centre would act obliquely, but that if put on afterwards it would only act vertically. In support of this, he mentioned that the arch above noticed was observed to move outwards and horizontally over 3½ inches at the haunches on the centre being struck. Such an outward horizontal spreading would necessarily entail horizontal compression of the filling or backing, which, when combined with its own weight, would bring an oblique pressure on the back of the arch, although not necessarily a normal one. On the other hand, it was observed that backing put on the arch after the centres were struck, although producing vertical or downward movements, caused no appreciable horizontal or outward spreading, and might, therefore, fairly be supposed only to act vertically, and not to produce any oblique or normal pressure on the arch. This seemed to show that the mode of action of the backing depended upon the time it was put on, whether before, or after the striking of the centres. The mortar used in constructing the arch alluded to was composed of one part of lime, one of sand, and one of pounded brick—a mixture generally used in India, and found to give excellent results.

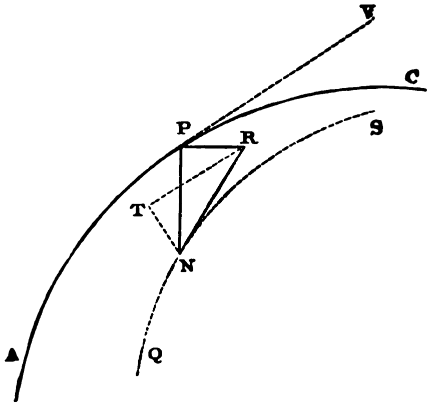
Mr. W. C. Unwin observed that Mr. Bidder's formidable indictment against Professor Rankine and other authorities would perhaps be elucidated by recollecting, that the term neutral axis was used by English writers in two entirely different senses. Sometimes it was employed to mean the axis along which there was no longitudinal stress—which was the sense in which Mr. Bidder used it; sometimes to mean the axis along which there was no longitudinal stress due to the bending moments,—and in this sense it was used by Professor Rankine in the instance quoted. It was quite reasonable that any writer should assign a meaning to the terms he used; and though, perhaps, a better term than neutral axis could be found, for the line through the centres of gravity of the sections, in the case of an arched rib, yet it was perfectly intelligible that that line should be termed the neutral axis with respect to the stresses due to the bending moments, and that use of the term in no way implied that there was no thrust along that axis.

He agreed with Mr. Airy that the use of the term rigid arch, in connection with a theory of the elastic arch, was unfortunate, because the term rigid had been used by mathematicians in a sense in which it would not apply to the arches considered in the Paper. The term suggested by Mr. Airy, viz., theory of the elastic arch, seemed perfectly good and sufficient; but if it were desired to be more explicit, the phrase, theory of the stiff elastic arch, might be used in preference to theory of the rigid arch.

He would next point out what appeared to him to be an error or oversight in the Paper:

To find the normal thrust F at the point P of the arch, Fig. 12, in the case of vertical loading, Mr. Bell proceeded thus (compare Fig. E, p. 78): Draw P N vertical, N R tangential to the curve of equilibrium, and P R horizontal. Then, according to Mr. Bell, N R was proportional to the normal thrust F on the normal section of the arch at P.[1] Now it was clear that N R could not be the normal thrust on the arch, for it was not usually parallel to the tangent P V to the mean fibre. To find the true normal thrust, N R must be resolved into a component parallel to P V, namely, R T and a component normal to the mean fibre, namely, T N. Then R T would be the normal thrust, and T N

Fig. 12.



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mbol F is used for the thrust on the normal sections of the arch he Paper. For instance, in the equation near the bottom of page 76.

the shearing force on the arch at P. Of course, in many cases, the curve of equilibrium was parallel, or nearly parallel, to the mean fibre, and then N R would coincide with T R; but in other instances it would not be so.

He did not agree with those who thought that Mr. Bell's process would be useless in the treatment of arches. In some cases, no doubt, analysis would furnish the stresses with less labour than Mr. Bell's method; but in other examples, as, for instance, the St. Pancras roof, the graphic method would be much the simplest. What Mr. Bell had done was this: he had used a known method of drawing curves of equilibrium—a method which enabled him to draw those curves without any calculation whatever. In the next place, he had proposed that that should be done by trial and error which it was difficult in many cases to do by calculation, namely, to choose amongst possible curves of equilibrium for a given loading, one from which the absolute measure of the stresses on any given arch could be deduced. He had shown that the method of trial and error was a practicable operation. In selecting the proper curve he had used a well-known property of curves of equilibrium, that the bending moments at any point of the mean fibre of the arch were proportional to the area between the mean fibre and the curve of equilibrium. But he proposed two entirely new tests, by which the proper curve could be discriminated. Without deciding whether these tests were the best which could be suggested, it might certainly be said that a direction had been pointed out in which the solution of the arch problem could be found.

In regard to the second test, it might be suggested that the use of this would be much facilitated by a simple construction. A curve could be drawn graphically, the areas between which and the mean fibre of the arch should represent the products of the areas between the curve of equilibrium and the mean fibre and the ordinates of the curve. Then Mr. Bell's second condition would be fulfilled, if the areas between this new curve and the mean fibre, on one side of the mean fibre, were equal to those on the other. And it would be easier to measure those areas by mechanical means if necessary, and also more accurate, than to measure a series of lines on the drawing, to find their products, and to sum them.[1]

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[1] Let A B, Fig. 13, be the mean fibre of the arch, C D the curve of equilibrum, and G H the chord of the arch, as in Mr. Bell's diagram. If the loading of the arch is vertical, draw *p q* vertical. From *p* draw any other line *p a*, and take *p a* =

There was only one other observation he wished to make, that was to direct attention to the statement with respect to the effect of the continuity of the members of a braced roof on the stresses. That statement was that, if the rafter were supposed continuous, the stresses would be only half as great as when the rafter was supposed jointed at the points where the bracing bars were attached. He thought that was impossible. The stresses on the rafters might be divided into two classes; those due to the forces acting along the bars, and those due to the bending moments on the bars. The former would be very little affected by the continuity of the rafters, the latter only could be reduced to one-half by making the rafters continuous instead of jointed. Now, in the ordinary calculations of roofs, allowance was made for this con-

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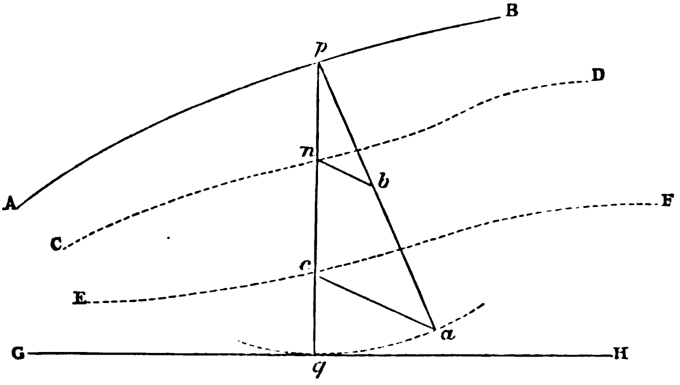
p q. At any distance *p b* take the point *b*, and join *b n*. Draw *a c* parallel to *b n*. Then, by similarity of triangles,

$$pc = \frac{pa \cdot pn}{pb} = \frac{pq\ \ pn}{pb}$$

Fig. 13.



That is, *p c* is proportional to *p n* . *p q*, and by properly selecting the constant distance *p b*, *p c* can be made to represent *p n* . *p q*, in any units required. Thus if the unit of bending moments and the unit of distance are equal, in other words, if the moment *p n* and the distance *p q* are to the same scale, then if $pb = 1$, $pc = pn \cdot pq$, in the same units. If the curve C D be outside the mean fibre, the lines must be drawn upwards.

Now let a series of points, such as *c*, be found, and the curve E F drawn through them. Then Mr. Bell's two conditions will be resolved into these: (1) $\Sigma\, pn = 0$, or the curve C D must cut off equal areas inside and outside the mean fibre A B. (2) $\Sigma\, pn \cdot pq = 0$ becomes $\Sigma\, pc = 0$, and, therefore, the curve E F must cut off equal areas inside and outside the mean fibre.

tinuity. The direct stresses were calculated on the assumption that the roof was jointed, because, so far as the direct stresses were concerned, it made little difference whether the roof were jointed or not. But in calculating the bending stresses, allowance was made for the continuity of each rafter. In ordinary calculations on roofs it was supposed that the rafters were jointed at the apex of the roof. Mr. Bell, however, had been able to go a step further, and to take into account the continuity of the rafters throughout the span.

Mr. BELL, in reply, said he felt much gratified by the consideration given to his Paper, and the favourable manner in which it had generally been received by the members of the Institution and also by the eminent foreign authorities, M. Gaudard, and Professor E. Collignon. He had been led to the production of this Paper by M. Gaudard's memoir "On Metal and Timber Arches;" for although the leading ideas had been familiar to him for some years, it was only on the occasion of the reading of that memoir before the Institution that these ideas took a definite shape.

M. Gaudard had remarked that the terms arising from deformation by flexure, longitudinal compression, &c., which had not been introduced into the formulæ of the Paper, were of slight consequence; and it would be observed that in the Paper it was shown how the value of these terms, and of any others which introduced small variations, might be estimated on the principle of the superposition of small changes.

Some explanation in regard to Equation (6), which Professor Collignon had slightly criticised, might here be given. M. Gaudard mentioned that he had tested Eq. (9), for a heavy arch rib, which had been deduced from Eq. (6), with the formula in his own memoir, and had found them to accord if the small terms were rejected; but without insisting on this test, the exactness of the formula might be shown as follows:

Supposing that the neutral line of the rib had been divided into a number of equal parts, each equal to Δs, and that, reckoning from the vertex, M_1, M_2, M_3, &c., were the values of M at the centres of each of these parts. Also let Δy_1, Δy_2, Δy_3, &c., be the corresponding values of Δy. Then the successive values of $\Sigma\,(M\,\Delta s)$ were—

$$\begin{array}{l} M_1 \cdot \Delta s \\ (M_1 + M_2)\,\Delta s \\ (M_1 + M_2 + M_3)\,\Delta s \\ (M_1 + M_2 + M_3 + M_4)\,\Delta s, \\ \quad \&c., \qquad\qquad \&c. \end{array}$$

Multiplying each of these by the value of Δy which corresponded to it, the successive values of $\Sigma (M \cdot \Delta s \cdot \Delta y)$ were—

$$(M_1 \Delta y_1) \Delta s$$
$$(M_1 \Delta y_2 + M_2 \Delta y_2) \Delta s$$
$$(M_1 \Delta y_3 + M_2 \Delta y_3 + M_3 \Delta y_3) \Delta s$$
$$(M_1 \Delta y_4 + M_2 \Delta y_4 + M_3 \Delta y_4 + M_4 \Delta y_4) \Delta s,$$

&c., &c.

The summation of these terms gave the successive values of $\Sigma \Sigma M \Delta s \Delta y$, which were—

$$\{M_1 \{ \Delta y_1 \} \Delta s$$
$$\{M_1 \{(\Delta y_1 + \Delta y_2) + M_2 \Delta y_2 \} \Delta s$$
$$\{M_1 \{(\Delta y_1 + \Delta y_2 + \Delta y_3) + M_2 (\Delta y_2 + \Delta y_3) + M_3 \Delta y_3 \} \Delta s$$
$$\{M_1 \{(\Delta y_1 + \Delta y_2 + \Delta y_3 + \Delta y_4) + M_2 (\Delta y_2 + \Delta y_3 + \Delta y_4) + M_3 \{(\Delta y_3 + \Delta y_4) + M_4 \Delta y_4\} \Delta s$$

&c., &c.

Now, considering the summation as stopped at any one of these terms, and a horizontal base line drawn through the point at which the summation ended, it would be obvious, on consideration, that the factors $(\Delta y_1 + \Delta y + \Delta y_3, (\Delta y_2 + \Delta y_3), \Delta y_3$, &c., of M_1, M_2, M_3, &c., were the vertical distances between the points of the rib, to which M_1, M_2, M_3, &c., corresponded, and the base line, or were the values of y, or $\Sigma (\Delta y)$, at each of these points. Hence

$$\Sigma \Sigma M \Delta s \Delta y = \Sigma (M y) \Delta s.$$

The double summation might thus be compared to an integral $\int \int z \, dy \, dx$, which expressed the volume of a solid of which the elementary portions were $z \, dy \, dx$, z being the height, and $dy \, dx$ the area of the base. If z be different for every different element $dy \, dx$ of base, the above integral could not be otherwise expressed; but if the solid be of such a form that sections made by planes parallel to this plane of $y z$ were rectangles, the heights being z and the bases y, the integral might be written $\int z \, y \, dx$. M might be likened to z in this integration, as it was not variable for every element Δs and Δy, but it was only variable along the curve of the rib.

Professor Clerk Maxwell's suggestion, that the varying internal conditions as to strength under long-continued strains of an important structure, such as the Britannia Bridge, might be ascertained by continuous observations of marks made at the points of greatest strain, was one in which Mr. Bell concurred; but there were as yet no experiments to show the minimum distance between the marks, which would give reliable information as to the state of strain on the metal, though he believed that a length of even less than 50 inches would be found quite sufficient.

In connection with Professor Maxwell's method of determining the stresses on an articulated structure, the theorem of M. Clapeyron deserved to be better known, as it was so simple as to be nearly self-evident. It might be stated thus: if upon any elastic structure, a load was applied by increments so gradual, that there was no loss of *vis viva*, except that due to the descent of the load through the distance by which the part of the structure immediately under the load was deflected, then the "work lost," or the load multiplied by one half the deflection, was equal to the aggregate *vis viva* stored up in the different parts of the structure by the elastic changes it underwent in consequence of the action of the load, assuming that the elasticity remained perfect, or that there was no 'set' or permanent deformation. Considering one of the pieces, for example, as a strut, compressed by the action of the load; the *vis viva* stored up in this strut, and which might be given out again if the load were removed, was equal to the force with which the strut was compressed, multiplied by one half the amount of compression on the whole length of the strut. If compressions and compressive forces were treated as positive, tensile forces and extensions would be negative, and the sum formed by adding the *vis viva* of each separate piece of the structure would contain no negative terms. The theorem was an extension of the principle of virtual velocities, M. Clapeyron having discerned that the virtual velocities of the different points of an elastic structure were the very extensions and compressions themselves. M. Lamé had demonstrated the theorem in its most general form,[1] giving, as an illustration, the application of it to the case of a triangular frame; and Professor Maxwell had generalized and simplified its application to a structure consisting of any number of pieces.[2] If it be applied to the case of a beam of rectangular section rested on end supports and loaded in the middle, by equating the aggregate of the "work done" in the compression and extension of the different elementary portions of the beam, to the "work lost" by the descent of the load, the central deflection of the beam was found to be the same as that derived from the ordinary formula.

In reference to the design which Professor Fleeming Jenkin had submitted, it might be remarked that it represented an articulated structure, and as such possessed the power of accommodating itself to a settlement of the abutments. If the top horizontal member and the arch were made stiff or rigid, this accommodating power would be to a great extent sacrificed, but there would be an increase of strength, though it was somewhat difficult to say to what amount, as the method of calculation for an articulated structure would no longer be applicable.

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[1] Lamé, "Leçons sur la Théorie Mathematique de l'Elasticité des Corps Solides," p. 82.

[2] "Philosophical Magazine," May, 1864.

The economy of a structure depended so much upon circumstances, that no attempt had been made in the Paper to compare different structures as to their relative economy; the object rather being to leave design free, because when the stresses on a structure could be accurately determined, the relative economy of that structure could be easily ascertained. It was shown however, both in the case of arched ribs and continuous beams, how to obtain the maximum structural economy, by making the moments of inertia of the transverse sections proportional to the stresses.

As an example of the graphic method of determining stresses, attention might be directed to the useful and beautiful diagrams of Professor Jenkin,[1] by which the stresses on all the parts of a framed structure could be ascertained, and which diagrams had the peculiar merit that each stress was checked by the closing in of the lines of the diagram, in somewhat the same manner as the closing in of the lines of a traverse survey.

In reply to Mr. Phipps, as to the drawing of the curve of equilibrium for an arch unequally loaded, with weights acting vertically, the method given was simply a corollary from the method for oblique forces, which latter Mr. Bell claimed as new. He quite agreed that Mr. Phipps, in his remarks on M. Gaudard's Paper, had correctly, although somewhat vaguely, stated the general principles on which the true curve of equilibrium was to be chosen. These general principles had not only been stated, but had been reduced to algebraical formulæ by M. Bresse, Dr. Rankine, and others; so that, as M. Gaudard had remarked, their theoretical truth seemed unquestionable. The design which Mr. Phipps had proposed met the difficulty of resisting the transverse strain at the haunches, when the bridge was only partially loaded, but it was doubtful whether it or the design proposed by Professor Fleeming Jenkin would be sensibly more economical than an ordinary arch rib made on the type of the St. Pancras roof, as it would be observed, on examining Figs. 13 and 14 of Plate III., that there was nearly as much transverse stress at the crown as at the haunches in the event of unequal loading.

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[1] "Trans. Royal Society of Edinburgh," vol. xxv., p. 441.

Mr. Heppel's design would perhaps be most effectual if applied to several spans, and the arch and top horizontal member made continuous over the piers; it would then be virtually a continuous beam of varying section.

Although, as Mr. Fletcher had remarked, great care was generally taken in constructing boilers to make them of correctly circular form, Mr. Bell thought this was a point which could not be too much insisted upon. The idea which had been elicited during the discussion, that the elasticity of the material of a boiler might be sufficient to allow of its sensibly changing its shape by the pressure of the steam, ought to be further examined; because, although this circumstance would increase the tendency of an incorrectly formed internal flue to collapse, it would, so far as it was operative, mitigate the danger of bursting consequent upon an incorrectness of the form of the external shell of a boiler. On the other hand, it seemed not unreasonable to suppose, that the plates of which a boiler was constructed would be weakened by being bent into a circular form, and that the tangential would be somewhat less than the direct tensile strength. He therefore thought that the recent introduction of "sectional boilers," or the making of several small boilers instead of one large one, was a step in the right direction.

Mr. W. Airy, assuming that the word "rigid" should be used in the sense of "inflexible," had objected to it as applied to an arch. But the word was only intended to be used in its commonsense meaning of "stiff" as in the translation of M. Gaudard's memoir, and it seemed as good a word as any of the others which had been proposed. The analogous term, "continuous beam," would indicate that "continuous arch" should mean a series of arches continuous over the piers, and the word "elastic," which had also been proposed, had become so nearly synonymous with india rubber, that it might have been more liable to have been misunderstood than the word "rigid." Perhaps the term "arched rib," although somewhat technical, would on the whole be least liable to objection. Mr. Airy had also stated, in regard to the stresses caused by a small alteration of the span of an arched rib, that it was an important matter, on account "of the difficulty of arriving at a result by short cuts, or rough and ready methods;" and, in the particular instance cited from the Paper, had remarked that the stress ought only to be ¼ ton per square inch, instead of ¾ ton, and that the "difference was caused entirely by the rough methods of approximation employed." In reply to this, Mr. Bell remarked that although, for the sake of simplicity, an idea had been introduced, drawn from the consideration of the curve of equilibrium, the integration of the expression arrived at was exact and without approximation, and the only steps in the process which could be called "rough" were the application of the formula to the circle instead of the parabola, the error introduced by which was too trifling to be worth notice, and the taking of Δx as equal to Δs in the integration, the error caused by which should be about 3 per cent., since the length of the semi-arc was 103, and the length of the semi-span 100 feet, the error being simply proportional to the error of Δs, and on the average Δs was thus to Δx as 103 to 100.

There should, then, *primâ facie*, be scarcely any error in the process worth considering, and this was shown by Mr. Airy's own investigation; because, although the mathematical part of it was unexceptionable, he had, by having performed the numerical calculation in a "rough" manner, given the value of the trigonometrical function $-\frac{3}{2} \sin a \cos a + a \left(\frac{1}{2} \sin {}^2a + \frac{3}{2} \cos {}^2a\right)$ when $a =$ 22° 37′, as ·005; whereas, on the calculation being correctly made, its true value was ·00124; and when this error in the investigation was corrected, the value of t would be found to be ·74 ton per square inch, instead of ·75, or ¾ per ton per square inch, as stated in the Paper.

Mr. W. H. Bidder had very properly called attention to the sense in which the term "neutral line" had been used, and had given some instructive diagrams to illustrate the changes of position which the point of separation between the compressed and extended parts of a rib underwent, by a change in the position of the line of force. This criticism had been so well answered by Mr. Unwin, that it seemed scarcely necessary to observe that the term "neutral line," defined, as had been remarked, to be neutral, not with respect to the total, but only to the transverse stresses, was very compendious, and probably the best that could be used. The term "axis of rotation," which had been proposed, besides having already been appropriated in questions connected with the motion of a solid body, would not really mean what was intended by "neutral line" in the Paper. To express this, it would require to be described as the "line passing through the axes of rotation of the cross sections," and this, in point of conciseness, was no improvement on "the line passing through the centres of gravity of the cross sections."

Mr. Bell was glad to find that Mr. Heppel, who, perhaps more than any other English Engineer, had paid special attention to the subject of continuous beams, had appreciated, and had so happily expressed, the peculiar advantages of solution by diagram. He quite agreed that the choice of method would depend upon the individual; but to those who could understand this mode of solution, it not only presented a perfect picture of the stresses at every point, but it also showed their variation from point to point, in a manner that was quite unapproachable by any algebraical formula. At the same time, he should be the last to undervalue the analytical method of solution, as it frequently led to results unattainable by diagram. To draw an instance from the subject of the present Paper, he did not see how Euler's theory of long pillars could be approached by the diagrammatic method of solution, and yet the results of that theory were attained with great facility by analysis.

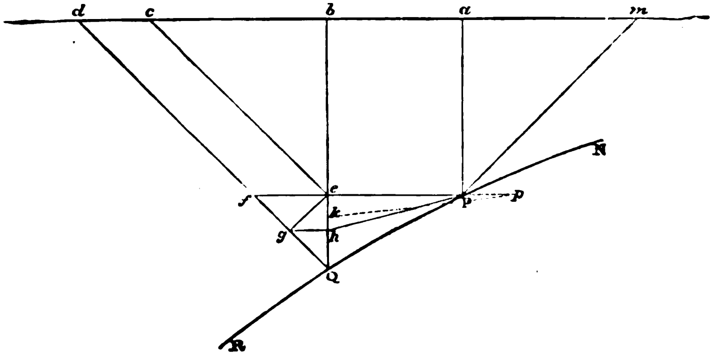
Major Browne's description of the manner in which a large brick arch had obtained a curve of equilibrium for itself was very interesting, and trenched upon the difficult question of the conditions of equilibrium of an arch consisting of small voussoirs, where the centres had been struck before the mortar had thoroughly set. As the joints could not have been brought into play, there would not be reactions perpendicular to their surfaces, but the whole substance of the arch was in the state of a partially elastic and coherent mass, like stiff clay. In regard to the apparently wholly vertical action of that part of the backing which was put on after the centres had been struck, it seemed just possible that no horizontal motion was observed because the arch had already come to its bearings.

Mr. Bell quite agreed with Mr. Unwin's criticism in regard to the normal thrust. It was, however, more a matter of preciseness of ideas than of any real importance, since at the points where the curve of equilibrium most differed from the neutral line of the rib in direction the bending moments were zero, and at the points where the bending moments were greatest the curve of equilibrium was sensibly parallel to the neutral line of the rib. He did not mean to assert, indeed he was far from thinking, that the method of solution by diagram which had been employed could not be further simplified. Mr. Unwin's constructive method of finding the products was to some extent a simplification, and would probably be used by those who were unfamiliar with the readiness by which products could be obtained by the use of the sliding rule. It was necessary however to remark, in regard to Mr. Unwin's statement, that the curve E F must cut off equal areas inside and outside the neutral line, that this was not quite exact, because it was the sum of the lines $p\ c$, which sum was not exactly proportional to the areas between the curves, which should be made equal to zero. In a flat arch, the error would be very slight, but in an arch of great rise, it might be considerable. If Mr. Unwin's lines *p c*, after having their lengths ascertained, were erected from the points *p*, at right angles to the neutral line of the rib, and a curve line drawn through their extremities, then the area intercepted between this curve and the neutral line of the rib ought to be made equal to zero, and the construction would be exact.

As the remarks in the Paper on the action of the backing of an arch seemed to have been understood in a sense somewhat different from what was intended, he thought it might be worth while to offer a few words in explanation, which, without entering into any theory as to the internal forces in a mass of earth, might yet illustrate the difference between the pressure of a fluid and that of a partially coherent solid.

In Fig. 14 let N P Q R be the back or extrados of an arch subjected to pressure, by a material of which the upper surface was

Fig. 14.



m b d. Consider a small portion P Q of this extrados, and draw the vertical lines P *a*, Q *b*, and the horizontal line P *e f*, cutting Q *b* in *e*. If the material pressing on the back of the arch were a perfect fluid, the vertical pressure on P Q might be represented by the column P *a b e*, and the horizontal pressure by a column whose base was Q *e*, and approximate height P *a*. In other words, P *e*, and Q *e*, the resultant of which was P Q, might be taken to represent the vertical and horizontal forces; and since P *e* and Q *e* were at right angles to the directions of the forces they represented, their resultant would be at right angles to P Q, or would be normal to the back of the arch. Now supposing the material to have such an amount of coherency as to stand at a natural slope or inclination to the horizon, draw the lines P *m*, Q *d*, at this inclination. There would then be no action on P Q from the parts of the backing *m* P N, *d* Q R, but the action would be confined to that of the piece in *m* P Q *d*. Draw *e c* parallel to Q *d*, and since the horizontal pressures of the pieces P *a m*, *e b c*, balanced one another, suppose for the present these pieces to be removed, and the action would then be confined to the pressure of P Q *b a*, and Q *e c d*. The weight or vertical pressure of the former might be represented by the line P *e*, and the weight of the latter, which was approximately equal to the weight of a column *b e* × *e f*, by *e f*. Draw *e g* at right angles to Q *d*, and *e g* would represent the force, exclusive of friction, requisite to balance the tendency of *e f c d* to slide down the plane Q *d*, and if *g h* were drawn horizontally to cut Q *e* in *h*, *e h* would be the resolved part of this force in a horizontal direction, the vertical component being destroyed by the reaction of Q *d*. The forces acting on P Q would then be represented by P *e* and *e h*, and since the resultant of these was P *h*, the pressure on P Q would be at right angles to P *h*. But the friction along Q *d*, and the cohesion of the material, would materially diminish the length of the line *e h* to some other length, as *e k*, while the length of the line P *e* would have to be increased to some other length, as *e p*, because the vertical pressure was not the weight of P *a b e* only, but of P *m c e*. Join *p*, *k*, and the resultant pressure on P Q would be at right angles to *p k*. Therefore, except in the case of wet backing, the pressure on P Q would be much more nearly normal to P *e* than to P Q. If the relative proportions of *p e* and *e k* could be determined, the curve of equilibrium for partially coherent backing might then be drawn by the method explained in the Paper.

December 12, 1871.

CHARLES B. VIGNOLES, F.R.S., President,
in the Chair.

It was resolved unanimously—That, considering the critical and painful condition of His Royal Highness the Prince of Wales, Hon. M. Inst. C.E., and the deep anxiety which the nation is now suffering, this Institution do show its sympathy in the general feeling by immediately adjourning.

ANNUAL GENERAL MEETING.

December 19, 1871.

CHARLES B. VIGNOLES, F.R.S., President,
in the Chair.

THE list of members prepared for Council, together with the record of the attendances of the Members of Council, in Council and at the Ordinary General Meetings, was taken as read, and the Ballot was declared open.

Messrs. C. Frewer, R. C. May, F. Murton, T. M. Smith, Francis Stevenson, Joseph Taylor, and John Thomson, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council for the ensuing year; and it was resolved that the ballot papers should be sent for examination every quarter of an hour that the Ballot remained open.

The Annual Report of the Council, on the proceedings of the Institution during the past year, was read. (*Vide* page 168.)

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council, to be printed and circulated with the Minutes of Proceedings, in the usual manner.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. Hutton Vignoles and R. C. May, for the readiness with which they undertook the office of Auditors of Accounts; and that Messrs. R. C. May and J. Wolfe Barry be requested to act as Auditors for the ensuing year.

Resolved,—That the practice of inserting in the balloting list the attendances of the Members of the Council be discontinued.

The Telford and Watt Medals, the Telford and Manby Premiums of Books, and the Miller Prizes, which had been awarded, were presented. (*Vide* pages 172—175.)

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents and other Members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Vignoles, President, for his strenuous efforts in the interests of the Institution, for his extraordinary attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Vignoles, President, returned thanks.

Resolved,—That the cordial thanks of the Meeting be given to Mr. Charles Manby, the Honorary Secretary, and to Mr. James Forrest, the Secretary, for their unremitting and zealous services on behalf of the Institution and of the profession.

Mr. Manby and Mr. Forrest returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year:—

President.

THOMAS HAWKSLEY.

Vice-Presidents.

Joseph Cubitt.
Thomas Elliot Harrison.
George Willoughby Hemans.
George Robert Stephenson.

OTHER MEMBERS OF COUNCIL.

Members.

James Abernethy.
Sir W. G. Armstrong, C.B., F.R.S.
William Henry Barlow, F.R.S.
John Frederic Bateman, F.R.S.
Joseph William Bazalgette, C.B.
Nathaniel Beardmore.
Frederick Joseph Bramwell.
George Barclay Bruce.
James Brunlees.
Charles William Siemens, F.R.S.
Sir Joseph Whitworth, Bart., F.R.S.
Edward Woods.

Associates.

Isaac Lowthian Bell.
Henry Bessemer.
William Cawkwell.

Resolved,—That the thanks of the Meeting be given to Messrs. Frewer, May, Murton, Smith, Stevenson, Taylor, and Thomson, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the Ballot Papers be destroyed.

[ANNUAL REPORT.

ANNUAL REPORT.

SESSION 1871-72.

THE Council elected at the last Annual Meeting to direct, manage, and superintend the affairs of the Institution, subject to the Royal Charter of Incorporation, and to the Rules and Regulations founded on that Charter, have now, on resigning the trust confided to them, to present an account of the state of the Institution, and to give an abstract of the proceedings during their term of office.

In the past session an Address was received from a numerous body of Members and Associates, stating it was in their opinion desirable, that the number of the Council should be increased from seventeen to twenty, the maximum permitted by the Charter, and that a "broader basis of election" of the Council should be adopted than that which had hitherto been in use. This Address was signed by 131 Members, being between one-fifth and one-sixth of the whole number of that class, and by 105 Associates, or about one-tenth of that class. As an examination of the names showed that the views thus expressed appeared to be coincided in by members resident in all parts of the United Kingdom, and belonging to the very varied classes composing the Institution, the Council considered that the Address might be taken as representing a wide-spread and general feeling.

With a view to the accomplishment of the objects set forth in the Address, it was therein submitted for the consideration of the Council, that three of the existing Bye Laws should be modified, and that a new Bye Law should be enacted. As this proposal involved grave and serious changes, and as it will be readily admitted that it is inexpedient to make any such alterations unless good and substantial reasons can be shown in support of them, the Council were naturally desirous of ascertaining what were the grounds upon which the recommendations were based.

In the Address, it was observed that the largely-increased number of Members, Associates, and Students was "one among several reasons" which rendered it advisable that the suggested amendments should be made. As, however, no other reason than the one mentioned was given, and as that in itself seemed insufficient to justify such a course, the Council resolved to invite a deputation of five of the Committee named in the letter accompanying the Address to attend a Special Meeting of Council, "in "order to explain more fully the reasons which had led to the "suggestion of alterations in and an addition to the Bye Laws." In reply to this invitation a letter was received from Messrs. George Berkley, George B. Bruce, W. B. Lewis, and C. W. Siemens, stating that "We are instructed by the Committee to say that the "Members and Associates who signed the Address have not "empowered any 'five Members' to explain to the Council the "reasons which led them to suggest alterations in and an addition "to the Bye Laws. We are also desired to say that, in the "opinion of the Committee, the only way to obtain the explanation which, apparently, the Council desire, will be to call a "meeting for the purpose. With a view to this, the Committee "will present a Requisition, in accordance with Clause 1, Section XIV. of the Bye Laws, if it will be more agreeable to "the Council that this course should be adopted, than that this "meeting should, without such requisition, be convened by the "Council."

As at the date of this communication the sessional meetings were concluded, it was intimated to the Committee that the course prescribed by the Bye Laws, and referred to in that communication, had better be followed, if the Committee desired to bring the matter formally under the notice of the Members. Accordingly, the Requisition was made, and a Special General Meeting of Members only was convened.

A full report of the proceedings at that Meeting, which was continued by adjournment, and at another General Meeting, has already been issued, and the substance of the decisions then arrived at has likewise been included in Volume XXXII. of the Minutes of Proceedings, sent to every Member and Associate. It will only, therefore, be necessary in this place to allude very briefly to some of the more salient points discussed at these meetings.

The suggestions may be said to have embraced two leading propositions:—First, an increase in the number of "other Members of Council," that is, other than a President and four Vice-Presidents, from twelve to fifteen, two of such additional Councillors to be from the class of Members, and one from the class of Associates; and, secondly, that each and every year two of the Members of Council,—who, in course of time, would necessarily have been the senior Members,—and two of the Associates of Council, should become ineligible for re-election until after the expiration of one year.

The Council, after mature deliberation, came to the conclusion "that the suggested increase in the number of the members of "Council was, in their opinion, neither necessary nor desirable for "efficient administration. If, however, it was the decided wish of "the Members that the representative body should be increased, "the Council would not offer any opposition; but it was thought "that in such an event the extension should be effected by the "introduction of country members on to the Council. With regard "to the second proposition, that there should be a rotation in the "Council, by the compulsory retirement each year of the two "senior Members, it was considered that such a measure would be "prejudicial and disadvantageous to the interests of the Insti-"tution, and should, therefore, be resisted."

At the first Special Meeting one of the members protested against its legality, on the ground that the additional Rule that had been proposed was repugnant to the Charter, inasmuch as its effect would be to limit and restrict the freedom of choice of Members to serve on the Council. The President having ruled that the Meeting should proceed, the first proposition, as to the increase in the number of the Council, was duly moved and seconded, and, after discussion, was declared to be carried. The second proposition was then moved and seconded; but before any decision was arrived at, the Meeting was adjourned. Subsequently, the mover and the seconder of the second proposition informed the Council that, at the adjourned Meeting, they should ask the permission of the Members present to withdraw the suggested new Bye Law, and the proposed alterations consequent thereon; and that permission was granted.

The Council on their part convened a second Special General Meeting, for the purpose of considering and deciding upon certain alterations in the Bye Laws and Regulations, which they recommended, and which it had been ascertained would be concurred in by the requisitionists. These alterations were suggested with a view to meet the desire which had been expressed, that members generally should have a greater range of choice in the selection of the Council than appeared to be afforded by the ordinary mode of preparing the Balloting List. The modifications finally adopted were,—that in future the Balloting List should contain the names of at least twenty-three in place of seventeen Members, and of at least six in place of four Associates, and that the names of persons proposed for the various offices should all be printed in the same character of type, and in alphabetical order under their respective classes.

In conformity with these new arrangements, the Council prepared the Balloting List, which has already been issued to all the Members.

As a supplement to this narrative there remains to be disposed of a subsidiary question—that of the propriety, or otherwise, of recording on the balloting lists the number of the attendances of the Members of Council in Council and at the Ordinary Meetings. Such a record has been kept for many years: it was not however until the Annual Meeting on the 19th of December, 1865, that these attendances were ordered to be printed. Having been so ordered, it is not in the power of the Council to make any alteration in the practice; but as it seems desirable that the custom should not be continued, and as its continuance would be the means of individualizing the old from the new names on the balloting lists —which it has been in part the object of the changes lately made in the Bye Laws to avoid—a resolution (of which due notice has been given) will be moved at this meeting, with the entire concurrence of the Council, to the effect that the attendances of the Members of Council in Council and at the Ordinary Meetings be not in future printed on the balloting lists.

As a means of judging how far the Institution has facilitated the acquirement of professional knowledge, and aided in promoting mechanical philosophy, during the past year, the Ordinary Meetings will now be referred to. These meetings afford an opportunity of exchanging ideas on different points of practice; and the Council must again congratulate the members on the thoroughness of the discussions, which have been praised by foreign Engineers for their completeness and impartiality. In selecting Papers for reading at these meetings, the endeavour is invariably made to choose such as are most likely to lead to useful discussions upon the various branches of the profession.

During the past session there were twenty-five Ordinary Meetings, when eighteen Papers were read, and nine evenings were entirely devoted to discussion. The subjects brought forward comprised—a record of further experiments as to the Strength of Portland Cement,—a description of the timber Cofferdams used in the execution of a part of the Thames Embankment,—a memoir on the theory and details of construction of Metal and Timber Arches,—descriptions of a wrought-iron Pier at Clevedon, of Viaducts across estuaries on the line of the Cambrian railway, and of the New Ross Bridge,—an investigation as to the Strength of Lock Gates,—accounts of Floating Docks, more especially of those at Cartagena and at Ferrol, as well as of the Basin, the Balance Dock, and the Marine Railways at the Austrian Naval Station of Pola, on the Adriatic,—a résumé of the present state of knowledge as to Phonic Coast Fog-signals,—an inquiry as to the Testing of Rails, with a description of a machine for the purpose,—an analysis as to Train Resistance on Railways,—a theoretical discussion as to the Archimedean Screw Propeller, or Helix, of maximum work,—the results of a series of experiments undertaken for the purpose of determining the best form of the Archimedean Screw for lifting water,—the principles and proportions of Centrifugal Pumps, with some particulars of their performances,—a description of two Blast Furnaces erected at Newport, near Middlesbrough, with full details of their cost,—an account of the Water Supply of the town of Paisley,—and a summary of the various processes that had been suggested for the Treatment of Town Sewage.

This brief recapitulation affords abundant evidence of the diversity of the questions discussed at the meetings. The two volumes of the "Minutes of Proceedings," numbering together 895 pages of letter-press, and 23 illustrative plates, besides numerous wood engravings, which were issued in the month of September, attest that, in the collection and dissemination of professional knowledge, the Institution is eminently progressive. And when it is remembered that these volumes emanate from a private Society, and are not the result of any aid, direct or indirect, from the State, as is frequently the case under similar circumstances in foreign countries, the Council believe that they must be regarded with unqualified satisfaction.

To the Authors of several of the communications the Council have had peculiar gratification in awarding, out of the Special Trust Funds, bequeathed or assigned for the purpose, the following Telford Medals and Premiums, Watt Medal, and Manby Premium:—

1. A Telford Medal, and a Telford Premium, in Books, to Bernhard Samuelson, M.P., M. Inst. C.E., for his "Description of two Blast Furnaces erected in 1870 at Newport, near Middlesbrough."

*2. A Watt Medal, and a Telford Premium, in Books, to Jules Gaudard, C.E., Lausanne, for his Paper on "The Theory and Details of Construction of Metal and Timber Arches."

3. A Telford Medal, and a Telford Premium, in Books, to Alexander Beazeley, M. Inst. C.E., for his Paper on "Phonic Coast Fog-Signals."

4. A Telford Medal, and a Telford Premium, in Books, to Thomas Dawson Ridley, Assoc. Inst. C.E., for his "Description of the Cofferdams used in the Execution of No. 2 Contract of the Thames Embankment."

5. A Telford Medal, and a Telford Premium, in Books, to James Price, M. Inst. C.E., for his Paper on "The Testing of Rails; with a description of a Machine for the purpose."

6. A Telford Premium, in Books, to Walter Raleigh Browne, Assoc. Inst. C.E., for his Paper on "The Strength of Lock Gates."

7. A Telford Premium, in Books, to Sir Francis Charles Knowles, Bart., M.A., F.R.S., for his Paper on "The Archimedean Screw Propeller, or Helix, of Maximum Work."

8. A Telford Premium, in Books, to Hamilton Ela Towle, of New York, for his "Account of the Basin, the Balance Dock, and the Marine Railways at the Austrian Naval Station of Pola, on the Adriatic."

9. A Telford Premium, in Books, to George Banks Rennie, M. Inst. C.E, for his "Account of Floating Docks, and more especially of those at Cartagena and at Ferrol."

10. A Telford Premium, in Books, to Arthur Jacob, Assoc. Inst. C.E., for his Paper on "The Treatment of Town Sewage."

11. The Manby Premium, in Books, to Wilfrid Airy, B.A., Assoc. Inst. C.E., for his Paper on "The Archimedean Screw for Raising Water."

The attendances at the Ordinary Meetings, which, in the five years from 1862–3 to 1867–8, had gradually increased from an average at each meeting of 152 to an average of 242, have, in the three subsequent sessions (since the completion of the new building), as steadily declined, until in 1870–1 the average attendance was only 169. Formerly one-half of those present at the

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* Has previously received a Telford Medal.

meetings were visitors, then the proportion became about one-third, and now it does not exceed one-fourth. This decrease in the relative numbers is doubtless due to the creation of the Student class, as many of that class, if not otherwise entitled to the privilege, would probably attend as visitors.

While the importance is generally recognised of making the Institution the depository of accurate information on the existing condition of knowledge and practice in different branches of Engineering, in all countries, and with regard to machinery and manufactures connected with the profession, it should also be understood, that the interest of the Ordinary Meetings, and the value of the "Minutes of Proceedings" (containing a record of the Papers read, and of the discussions upon them, at these Meetings), can only be maintained by the members of all classes exerting themselves to prepare, or to assist in the preparation of, communications of merit, originality, and research. It is hoped that the members generally will use their utmost endeavours to obtain for the Institution Papers of a complete and comprehensive character, upon some of the topics at present engaging the attention of Engineers. A revised list of Subjects upon which (among others) communications are deemed desirable was issued during the recess.

It has been remarked, in previous Reports, that the Council were desirous of appending to the Minutes of Proceedings the details and results of Experiments or Observations connected with Engineering science or practice—such as the Strength of Timber of large dimensions when used as beams, struts, &c., the failure of Arches and of Retaining Walls, the Discharge of Water through apertures of various forms and of Gas through pipes, the Strength of Iron, Steel, &c. Every engineer has constant opportunities of thus aiding the cause of science; and even although in all cases such results of experience may not in themselves be sufficient to form the subject of a Paper to be read at a meeting of the Institution, yet when systematically recorded and published, they may help to elucidate many points that are now obscure, and lead to valuable deductions hereafter.

The Council regret that only seven communications were received from Students of the Institution. These Papers were read and discussed at six Supplemental Meetings, and to the Authors of these essays, as an encouragement to them and to the other Students, Miller Prizes have been awarded :—

1. A Miller Prize to Frederick Harry Mort, Stud. Inst. C.E., for his Paper on "Prussian Railways; their Construction, Cost, and Financial Results."
2. A Miller Prize to George Gatton Melhuish Hardingham, Stud. Inst. C.E., for his Paper on "Practical Aeronautics."
3. A Miller Prize to Arthur Turnour Atchison, B.A., Stud. Inst. C.E., for his Paper on "The Theory of Energy, and its application in the form of Heat to the Steam Engine."
4. A Miller Prize to Henry Francis Joel, Stud. Inst. C.E., for his Paper on "Bricks and Brickwork."
5. A Miller Prize to William Tweedie, Stud. Inst. C.E., and a Miller Prize to Francis Wilton, Stud. Inst. C.E., for their Paper on "The Calculation and Designing of Girders."
6. A Miller Prize to Henry Oliver Smith, Stud. Inst. C.E., for his Paper on "Materials employed in Sewer Construction."
7. A Miller Prize to Killingworth William Hedges, Stud. Inst. C.E., for his "Description of the Pumping Machinery employed at the Works of the Amsterdam Canal."

The Council are glad to be in a position to state, on the authority of the Members who kindly presided at these Supplemental Meetings, that the Papers showed much ability, even when on obscure subjects,—that they were clear, comprehensive, well written, and well read by the respective Authors,—that the discussions were sustained with spirit and intelligence,—and that the opportunity thus afforded to the younger members of the profession must be very instructive to them, and is well calculated to contribute to their improvement.

On the invitation of our Associate, Colonel Clarke, C.B., R.E., the Director of Engineering and Architectural Works to the Admiralty, the Students of the Institution, who were accompanied by the President and several Members of the Council, had last summer an opportunity of inspecting the extensive works in progress at Portsmouth Dockyard; and for the great trouble taken to impart every possible information to the younger members of the profession the warmest thanks of the Society have been tendered to Colonel Clarke.

In regard to the Indian Civil Engineering College at Cooper's Hill, the Council submitted to the Secretary of State for India, their reasons for thinking that such a mode of recruiting the Engineering establishment of the Public Works Department was neither necessary nor politic. A copy of their Minute, with the correspondence on the subject, is given at the end of this Report. In reply to this communication, the Duke of Argyll expressed regret that the course he had felt it his duty to take in the matter had not met with the approval of the Council of the Institution of Civil Engineers.

The accessions to the Library have been more numerous than in any previous year. These have been acquired principally by presentation, the number of purchases having been somewhat smaller than usual. A complete Catalogue of the works thus obtained is given in the Appendix to this Report under the names of the Authors; while a list of the donors is stated separately. Most valuable reports on public works have been received from the India and the Colonial Offices, as well as from the heads of departments of some of the Colonies, and these reports have been consulted on several occasions by colonial engineers temporarily staying in this country. It is hoped that the members residing abroad will do all in their power to assist in making these collections as complete as possible, since the reports on public works in the Colonies are not, as a rule, for sale in England, and are not readily accessible elsewhere.

During the recess the books have been rearranged on the shelves, with a view to incorporate the additions of the last three years, which had been kept separate. The cases have been lettered and numbered, and a catalogue marked in accordance, showing the case and shelf where each book may be found. So far as can be ascertained, the publications of every engineering society in existence are obtained in exchange for the publications of the Institution.

It cannot be too often repeated that every engineer should send to the Institution copies of all his published reports, and should aid in obtaining for the library a complete series of documents, however brief or however unimportant they may appear, relating to any work upon which he may be engaged, as it is by such means that the materials for compiling the histories of engineering undertakings are provided.

One present received during the year must be specially noticed—a marble bust of our late Associate, Mr. Brassey—the gift of his eldest son, also an Associate, who sends it in the "confident belief "that the memorial of one who always felt the deepest interest in "the success of the Institution, and who had devoted a busy life "to the execution of the skilful designs of very many of the past

" and present members of the society, will be valued." The Council have already tendered to Mr. T. Brassey, M.P., their best thanks for this very acceptable gift, and have intimated to him that the fact of this presentation should be conveyed to the members at the Annual Meeting.

In consequence of the great and increasing number of applications of late years, for admission into the Institution, and for transfer from the class of Associate to that of Member, the attention of the Council has been repeatedly given to the question of the Qualifications of Candidates. It is considered that the provisions of the Bye Laws founded upon the Charter, if strictly adhered to, are amply sufficient, without alteration, to insure the admission only of those whose avocations and antecedents are such as to justify their election. But while the Forms of Recommendation appended to the Rules and Regulations, and the requirements indicated thereon, do not seem to need any modification, it is deemed desirable to point out that, according to the spirit of the Bye Laws, the qualifications must in all cases be set forth with the utmost precision, and in considerable detail, in order to enable the Council, upon whom the classification devolves, and the members, with whom the subsequent election rests, to form a correct opinion as to the nature of the practice, the extent of the experience, and the degree of responsibility of every candidate. It has, therefore, been determined to print on all the Forms revised instructions for filling up the statement of qualifications; and in future only these Forms—copies of which have been sent to all the members—will be recognised. The Members and Associates are particularly requested not to sign any nomination paper unless they have a *personal knowledge* of the career of the candidate, and are fully satisfied that his position and attainments are such as to render him in every respect worthy of the distinction he seeks.

The tabular statement of the transfers, elections, deceases, and resignations of the members of all classes during the years 1869–70 and 1870–71 (taking into consideration the names which have been erased from the Register) is as follows:—

YEAR.	Honorary Members.	Members.	Associates.	
1869–70.				
Transferred to Members . .	..	..	19	
Elections	..	42	114	156—42 = 114
Deceases	..	17	20	
Resignations	..	..	4	42
Erased from Register . . .	..	..	1	
Members of all Classes on the Books, 30th November, 1870	16	699	988	1,703
1870–71.				
Transferred to Members . .	..	..	11	
Elections	..	26	102	128—45 = 83
Deceases	2	11	22	
Resignations	..	..	4	45
Erased from Register . . .	..	1	5	
Members of all Classes on the Books, 30th November, 1871	14	724	1048	1,786

This represents a net effective increase of 83, or 5 per cent. during the last twelve months. In the five preceding years this increase was 136, 94, 116, 40, and 114, and the percentages were 11¼, 7, 8¼, 2¾, and 7, respectively. Rather more than one-tenth of the Members (actually 76) are life subscribers; while only 52 Associates, or one twentieth of the whole number, have compounded for their annual payments. About four-ninths of the Members and Associates are resident in London and its vicinity, one-third in other parts of the United Kingdom, and the remaining two-ninths in British possessions abroad and in foreign countries.

With regard to the class of Students attached to the Institution, there were on the books at the date of the last report 173. The number admitted during the past session was 50; and the deductions include 2 deaths, 7 resignations, and 11 elected to the class of Associates; so that the net increase has been 30, bringing up the present total to 203, being an increase of 17 per cent. in the past twelve months.

Ten years ago there were on the register 22 Honorary Members, 369 Members, 542 Associates, and 12 Graduates, together amounting to 945; now the gross number is 1,989.

The deceases during the past year have been at the rate of 20 per thousand of the present number of members, and include the following:—

HONORARY MEMBERS: *Field Marshal Sir* John Fox Burgoyne, Bart., G.C.B., and *Sir* John Frederick William Herschel, K.H., both of whom had been borne on the register for thirty-three years.

MEMBERS: Joseph Hamilton Beattie (14), John George Blackburne (16), Herbert Louis Augustus Davis (4), Robert Benson Dockray (28), Philip Hardwick, R.A. (47), Albinus Martin (22), James Newlands (23), Josiah Parkes (48), Samuel Power (21), Yman D. C. Suermondt (49), and Thomas Wicksteed (34), who had belonged to the Institution for periods varying from 49 to 4 years, as recorded against each name—the average of the whole being nearly 28 years.

ASSOCIATES: John Hastings Babington (2), *Captain* George Baillie (10), Thomas Brassey (19), Samuel Thomas Cooper (4), Ohanes Dadian (27), *Lieut.-General Sir* William Thomas Denison, K.C.B. (34), Arthur Field (2), Joseph Freeman (21), Samuel Tate Freeman (5), Charles Frodsham (25), Thomas William Gardner (5), Henry George Hulbert (4), Henry de la Poire Murphy (2), Edward Mosely Perkins (28), Edward Price (15), Alfred Stansfield Rake (8), Henry Yarker Richardson (3), Robert Ritchie (26), Henry Beadon Rotton (4), Octavius Henry Smith (26), *Colonel* James Rogers Western (29), and Clement Wilks (2)—the average number of years that the Associates had been on the books is thus less than 14.

The following *Associates* having tendered their resignations have been permitted to retire from the Institution:—William Clarke, George Hallen Cottam, William Anthony Matthews, and *Captain* Henry John Yeatman.

Appended to this Report will be found the Financial Statement for the past twelve months, as certified by the Auditors, after examining the accounts and the vouchers. This statement, when compared with the similar abstract for the preceding year, shows slightly diminished receipts, due to a smaller number of elections, while the disbursements have been considerably less, although the liabilities are all promptly paid as they are incurred. The receipts last year from annual subscriptions, interest on investments not in trust, and miscellaneous items, amounted to £6,022 9*s.*, from all fees on admission and life compositions to £1,201 4*s.*, and from dividends on trust funds to £411 16*s.* 4*d.*, together £7,635 9*s.* 4*d.* The disbursements on the general account were £5,019 3*s.* 11*d.*, in respect of the new building a further sum of £214 13*s.* 10*d.*, and for premiums under trust £261 1*s.* 8*d.*, together £5,494 19*s.* 5*d.* A sum of £2,179 10*s.* 8*d.* has been invested in the purchase of £1,500 London, Brighton, and South Coast Railway

Four and a Half per Cent. Debenture Stock, and of £275 17*s.* and £442 6*s.* Three per Cent. Annuities, the two latter amounts representing the balances of unexpended income arising from the dividends of the Telford and the Miller Trust Funds respectively, during the years 1866–67–68–69 and 70. It may be mentioned that the annual expenditure last year was £866 in excess of what it was five years ago, but in the same time there has been a gain in the receipts of £1,285, both these sums being exclusive of the trust funds. In this period there has been an increase in the number of members of all classes, including Students, of 650.

The summary of the Receipts for the last two years is as follows:—

	1870.						1871.					
	£.	*s.*	*d.*	£.	*s.*	*d.*	£.	*s.*	*d.*	£.	*s.*	*d.*
From subscriptions, and sundries .	5,289	16	0				5,592	9	0			
„ dividends on investments not in trust	293	7	4	5,583	3	4	430	0	0	6,022	9	0
„ Fees, Building and Publication Funds on election, and life compositions	. .			1,757	3	6	. .			1,201	4	0
„ dividends on Trust Funds . . .	. .			390	19	8	. .			411	16	4
„ Appold Bequests	. .			1,800	0	0						
Totals . .	. .			£9,531	6	6	. .			7,635	9	4

The Expenditure during the same period has been:—

	1870.						1871.					
	£.	*s.*	*d.*	£.	*s.*	*d.*	£.	*s.*	*d.*	£.	*s.*	*d.*
To disbursements, including Minutes of Proceedings (less repayment on that account) .	6,134	14	2				5,019	3	11			
„ New building .	66	17	0				214	13	10			
„ Premiums under Trusts (less repayment for extra cost of binding)	242	17	1	6,444	8	3	261	1	8	5,494	19	5
„ Investments:—												
Telford Fund (unexpended income)	. .			. .			254	9	7			
Miller Fund (ditto)	. .			. .			408	0	4			
General account .	. .			2,968	15	6	1,517	0	9	2,179	10	8
Totals . .	. .			£9,413	3	9	. .			£7,674	10	1

There has been a further slight expenditure, on account of the new building, for contract extras and furniture (as already stated), of £214 13*s.* 10*d.*, bringing up the total outlay to this date to £18,491 13*s.* 2*d.* The Architect has been desired to mature his designs for the decoration of the Theatre and other rooms, so that the work may be completed during the next recess.

The Funds of the Institution consisted on the 30th of November last of

I. General Funds.

				£.	*s.*	*d.*	£.	*s.*	*d.*	£.	*s.*	*d.*
Institution Investments:—												
Great Eastern Railway Four per Cent. Debenture Stock				3,650	0	0						
London and North Western ditto				1,162	0	0						
London, Brighton, and South Coast ditto				1,000	0	0						
North Eastern ditto				1,500	0	0						
Great Northern ditto				1,000	0	0						
Manchester, Sheffield, and Lincolnshire Railway Four and a Half ditto				1,000	0	0						
London, Brighton, and South Coast ditto				1,500	0	0						
New Three per Cents.				1,344	1	8						
										12,156	1	8
II. Trust Funds.												
1. Telford Fund:—												
Three per Cent. Consols	£2,839	10	6									
Three per Cent. Annuities	2,570	5	1									
				5,409	15	7						
Unexpended Income, Three per Cent. Consols	2,377	10	6									
Ditto, Annuities	476	8	5									
				2,853	18	11						
							8,263	14	6			
2. Manby Premium:—												
Great Eastern Railway Five per Cent. Preference Stock							200	0	0			
3. Miller Fund:—												
Lancashire and Yorkshire Railway Four per Cent. Debenture Stock	£2,000	0	0									
Great Eastern ditto	1,100	0	0									
				3,100	0	0						
Carried forward				3,100	0	0	8,463	14	6	12,156	1	8

II. TRUST FUNDS—*continued.*

		£. s. d.	£. s. d.	£. s. d.
Brought forward		3,100 0 0	8,463 14 6	12,156 1 8
Unexpended Income, Three per Cent. Consols	582 18 6			
Ditto, Annuities	691 5 8			
		1,274 4 2		
			4,374 4 2	
				12,837 18 8

	£. s. d.
Total Nominal or par Value of different Securities . . .	24,994 0 4
Cash in the hands of the Treasurer, Dec. 1, 1870 . .	377 12 3
" " Secretary	1 10 9
Together amounting to	£25,373 3 4

as against £23,145 14*s.* 9*d.* at the date of the last Report; showing an increase in the Funds of £2,227 8*s.* 7*d.*, of which £2,179 10*s.* 8*d.* has been the sum actually invested, £38 12*s.* 4*d.* represents the higher nominal or par value of the different securities purchased in the year beyond the amounts paid for them, and £9 5*s.* 7*d.* is the excess in the cash balances beyond what it was then. It should be understood that, in this statement of the Funds belonging to, or under the charge of the Corporation, no account is taken of the value of the lease of the premises, of the books in the Library, of the portraits, of the stock of Minutes of Proceedings, or of other property and effects.

The following is a Summary of the different Securities in which the above Funds are placed:—

	£. s. d.	£. s. d.
Government Stocks:—		
Three per Cent. Consols	5,799 19 6	
Three per Cent. Annuities	3,737 19 2	
New Three per Cents.	1,344 1 8	
		10,882 0 4
Great Eastern Railway:—		
Five per Cent. Preference Stock	200 0 0	
Four per Cent. Debenture Stock	4,750 0 0	
		4,950 0 0
Lancashire and Yorkshire Railway:—		
Four per Cent. Debenture Stock		2,000 0 0
London and North Western Railway:—		
Four per Cent. Debenture Stock		1,162 0 0
London, Brighton, and South Coast Railway:—		
Four per Cent. Debenture Stock		1,000 0 0
Four and a-Half per Cent. Debenture Stock . . .		1,500 0 0
North Eastern Railway:—		
Four per Cent. Debenture Stock		1,500 0 0
Great Northern Railway:—		
Four per Cent. Debenture Stock		1,000 0 0
Manchester, Sheffield, and Lincolnshire Railway:—		
Four and a Half per Cent. Debenture Stock . . .		1,000 0 0
Total Nominal or par Value . .		£24,994 0 4

Although every effort has been made to reduce the arrears of contributions, the total amount of Subscriptions still remaining due on the 30th November last, including the current year, is:—

		£.	s.	d.	£.	s.	d.
For 1871.	From members of all classes residing abroad	33	1	6			
	Ditto, in the United Kingdom	168	0	0			
					201	1	6
For 1870.	From members of all classes residing abroad	12	1	6			
	Ditto, in the United Kingdom	27	6	0			
					39	7	6
	Total				£240	9	0

The Council felt compelled, after suitable remonstrance, to erase from the Register the names of 1 Member and of 5 Associates, as previously stated, from whom, at the date of such erasure, there was a gross amount due of £44 12*s.* 6*d.* On the other hand, under the powers vested in the Council by Clause 11, Section VI., of the Bye Laws, one old Member has been enrolled as a life subscriber, in consideration of the presentation to the Institution of a valuable collection of Engineering books; and the arrears due from 3 Members and 3 Associates—together amounting to £84 10*s.* 6*d.*—have been remitted, in consideration of their not at present carrying on a lucrative practice, and of their long connection with the Institution, their subscriptions having been regularly paid for periods of 16, 16, 12, 19, 16, and 25 years respectively.

On the occasion of the Conversazione given by the President, in the rooms of the Institution, at the close of the session, a collection was made of paintings and water-colour drawings, by ancient and modern masters, depicting some engineering work, object, or matter of interest, set in its appropriate landscape. The task was difficult, but, although the first attempt of the kind, the display was thoroughly good in an artistic sense, and most interesting from a professional point of view. At the same time a novelty was introduced into the exhibition of engineering models, small machines, contrivances and instruments, by forming a more or less complete series of two or three special subjects, in addition to the miscellaneous objects. This year the subjects chosen were telegraph and electrical apparatus, all the instruments being shown in action; contrivances connected with the economical use and distribution of water, principally as supplied at a high pressure and under constant service; and a series of modern, chiefly British, small arms of precision. These changes have been regarded as decisive improvements, and as tending to introduce a principle and a limit which may serve as a useful guide in future.

This Report may be appropriately concluded in the words of a former President, Sir John Rennie, who, in addressing the members on a similar occasion, in 1847, remarked that—

"An Institution like this can only be of use so long as it is well supported by its members, and its reputation as a scientific body is preserved, and then only so long as they all feel that their own individual benefit, or rather credit, is involved in the prosperity of the general body."

APPENDIX.

THE INDIAN CIVIL ENGINEERING COLLEGE.

I.

Extract from the Minutes of the Council of The Institution of Civil Engineers, March 15*th*, 1871.

"THE attention of the President and Council of the Institution of Civil Engineers having been called to the proposed Indian Civil Engineering College, they respectfully submit to His Grace the Secretary of State for India that the establishment of the College is unnecessary, and that it is not likely to be attended with favourable results. This measure implies that the present means of attaining an adequate Engineering training in this country are defective, but the President and Council are of opinion that there has been no sufficient enquiry into those means to justify such a conclusion.

"It has been stated that the Government of India has been disappointed with some of the young men who, during the last few years, have been chosen by competitive examination as Junior Assistants. The President and Council submit that such a mode of selection could only lead to disappointment, as it in no way tested any of the qualifications of an Engineer, excepting a retentive memory and a certain aptitude for figures. On the other hand it is admitted that Engineers of tried experience, educated in the usual way, and appointed to the Public Works Department of India after careful personal enquiry into their antecedents, have, with few exceptions, given great satisfaction, and many of those recently selected have received rapid promotion.

"Having regard to the theoretical preparation for the profession of an Engineer, and to the technical education so far as it can be obtained in Colleges, there are many well-known establishments in the United Kingdom where such instruction has been successfully given for many years, under Professors and Masters of proved ability; and it is no reflection upon those whom the Secretary of State may select as Professors, to presume that they are not likely to surpass all who have preceded them in a similar capacity elsewhere.

"The practical training of Engineers attainable in any College is at best imperfect, and the conviction of this fact has probably led the Secretary of State to propose that 'two terms at least in the third year, with the intervening vacation, shall be passed by the Student under a Civil or Mechanical Engineer, or partly under each.' The duration assigned to this training is insufficient to prepare the Students properly to fulfil the duties of Assistant Engineers; and they will therefore be reduced to the necessity of learning their profession practically, by a system of trial and error, at the expense of the people of India.

"According to the ordinary system by which Engineers are trained in this country, they are brought up under men of varied practice and distinct orders of mind; and during the period of probation upon works, as pupils, their character is developed and their fitness or otherwise for the profession is ascertained. But in the proposed College the minds of the pupils will all be moulded to the same forms. There will be none of the emulation of different schools of thought and action, and none of that independence and originality of resource which have produced the best Engineers.

"In reference to the alleged failure to obtain the requisite number of competent Civil Engineers for India, the President and Council submit that it may be attributed, in the first instance, to the inadequacy of the emolument hitherto offered; and, secondly, to the conditions of the service, which are less favourable than in some other Departments of the Government, having been established, as the President and Council are informed, on the basis assigned to Native as distinguished from European officials. The first of these impediments will be removed by the promised increase of remuneration; and, if the Government carry out more widely the improvements in the Rules of the Service, which have been commenced, it is the opinion of the President and Council that there will not be any difficulty in supplying Engineers for India from existing sources, without establishing a special Government College—the result of which must inevitably lead to the creation of an injurious monopoly.

"The Empire of India is now one of the largest fields of action for British Engineers; and as the President and Council feel assured that by the course about to be adopted, India will be supplied with Engineers of inferior practical qualifications, they consider it to be their duty to record their respectful but earnest protest.

"Signed, on behalf of the Council,
CHARLES B. VIGNOLES,
"*President.*"

(A true Copy.)

JAMES FORREST,
Secretary.

March 18*th*, 1871.

II.

"THE INSTITUTION OF CIVIL ENGINEERS,
(*Established* 1818. *Incorporated by Royal Charter*, 1828.)
"25, *Great George Street, Westminster, S.W.*
"18*th March*, 1871.

"MY LORD DUKE,

"I have the honour to transmit to you the accompanying Minute of Council of the Institution of Civil Engineers, and I am requested to state that if your Grace should desire any further explanation, I shall be ready to attend your Grace's orders, either alone, or with a deputation of the Council.

"I have the honour to be,
"My Lord Duke,
"Your Grace's most obedient Servant,
"CHARLES B. VIGNOLES,
"*President.*

"*To His Grace*
"THE DUKE OF ARGYLL, K.T., &c., &c., &c.,
"*Secretary of State for India.*"

III.

"INDIA OFFICE, 28*th June*, 1871.

"SIR,

"I am directed by the Duke of Argyll to acknowledge, with apologies for delay in so doing, your letter of the 18th March, enclosing a Minute of the Council of the Institution of Civil Engineers, on the proposed Indian Civil Engineering College, and offering, should his Grace so desire, to furnish him personally with further explanation of the Council's views on the subject.

"In reply, I am to state that the Minute appears to the Duke of Argyll to be too explicit to require any additional elucidation, and to express at the same time his Grace's regret that the course which he has deemed it his duty to take in the matter to which the Minute refers has not met with the approval of the Council of the Institution of Civil Engineers.

"I am, Sir,
"Your obedient Servant.
(Signed) "HERMAN MERIVALE.

"CHARLES B. VIGNOLES, Esq."

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	*s.*	*d.*	£.	*s.*	*d.*
To Balance in the hands of the Treasurer				374	2	2
— Subscriptions and Fees:—						
Arrears	148	1	0			
Current	5,338	4	0			
Subscriptions for 1872	42	0	0			
Fees	403	4	0			
Life Compositions	78	15	0			
				6,010	4	0
— Building Fund				654	3	0
— Publication Fund				65	2	0
— Council Fund				50	0	0
— Publications:—Sale of Transactions				202	1	11
— Telford Premiums:—Repayment of Cost of Binding, &c.				17	19	3
— Telford Fund:—						
Dividends, 1 Year, on £2,839. 10*s.* 6*d.*, Three per Cent. Consols	83	7	8			
Ditto, 1 Year, on £2,570. 5*s.* 1*d.*, Three per Cent. Annuities	75	10	6			
Ditto, 1 Year, on £2,377. 10*s.* 6*d.*, Three per Cent. Consols (Unexpended Dividends) . .	69	18	6			
Ditto, 1 Year, on £476. 8*s.* 5*d.*, Three per Cent. Annuities (Unexpended Dividends) . . .	13	19	8			
				242	16	4
— Manby Premium:—						
Dividends, 1 Year, on £200, Great Eastern Railway Five per Cent. Preference Stock				9	16	3
— Miller Fund:—						
Dividends, 1 Year, on £2,000, Lancashire and Yorkshire Railway Four per Cent Debenture Stock.	78	10	0			
Ditto, 1 Year, on £1.100, Great Eastern Ditto .	43	6	7			
Ditto, 1 Year, on £582. 18*s.* 6*d.*, Three per Cent. Consols (Unexpended Dividends)	17	1	4			
Ditto, 1 Year, on £691. 5*s.* 8*d.*, Three per Cent. Annuities (Unexpended Dividends) . .	20	5	10			
				159	3	9
— Institution Investments:—						
Dividends, 1 Year, on £3,650, Great Eastern Railway Four per Cent. Debenture Stock. .	143	2	7			
Ditto, 1 Year, on £1,162, London and North Western Ditto	45	12	1			
Ditto, 1 Year, on £1,000, London, Brighton and South Coast Ditto	39	5	0			
Ditto, 1 Year, on £1,500, North Eastern Ditto .	58	17	6			
Ditto, 1 Year, on £1,000, Great Northern Ditto	39	5	0			
Ditto, 8½ Months, on £1,000, Manchester, Sheffield, and Lincolnshire Railway, Four and a Half per Cent. Ditto	31	7	3			
Ditto, ½ Year, on £1,500, London, Brighton, and South Coast Ditto	33	0	11			
Ditto, 1 Year, on £1,344. 1*s.* 8*d.*, New Three per Cents.	39	9	8			
				430	0	
— Donations to Library				14	4	0
Carried forward . . .				£8,229	12	8

from the 1st DEC., 1870, *to the* 30th NOV., 1871.

PAYMENTS.

Cr.	£.	*s.*	*d.*	£.	*s.*	*d.*
By Balance due to the Secretary				4	4	9
— House, Great George Street, for Rent, &c.:—						
Repairs	98	5	8			
Rent	640	0	4			
Rates and Taxes	72	1	10			
Insurance	20	11	6			
				830	19	4
— Salaries				1,000	0	0
— Clerks, Messengers, and Housekeeper				364	15	0
— Postage and Parcels:—						
Postage	68	2	11			
Parcels	7	13	5			
				75	16	4
— Stationery, Engraving, Printing Cards, Circulars, &c.				148	8	8
— Coals, Candles, Oil, and Gas:—						
Coals	29	9	6			
Candles	0	2	5			
Oil	0	8	6			
Gas	54	5	0			
				84	5	5
— Tea and Coffee				35	2	10
— Library:—						
Books	77	2	7			
Periodicals	21	5	0			
Binding Books	38	9	5			
Council Gift	39	7	8			
Supplement to Catalogue	143	5	3			
				319	9	11
— Publication, Minutes of Proceedings				1,804	0	4
— ,, General Index to Ditto, Vols. XXI. to XXX.				170	10	9
— Telford Premiums				181	3	9
— Watt Medals				8	3	0
— Manby Premium				10	2	0
— Miller Prizes				87	15	2
— Diplomas				31	12	10
— Manuscripts, Original Papers, and Drawings				0	9	4
— Annual Dinner				110	14	6
— Winding and Repairing Clocks				2	8	6
— Incidental Expenses:—						
Christmas Gifts	1	16	0			
Assistance at Meetings	10	4	6			
Ditto at Supplemental Meetings for Students	3	7	6			
Beating Carpets and Sweeping Chimneys	1	5	0			
Household Utensils, Repairs, and Expenses	75	1	0			
				91	14	0
— Engineering Education				91	14	10
— Legal Expenses				51	0	3
Carried forward				£5,504	11	6

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*cont.*

Dr.	£.	s.	d.
Brought forward	8,229	12	8
To Benevolent Fund, for Disbursements in 1870 and 1871 . .	57	12	5
	£8,287	5	1

from the 1st DEC., 1870, *to the* 30th NOV., 1871.

PAYMENTS—*cont.*

Cr.	£.	s.	d.	£.	s.	d.
Brought forward				5,504	11	6
By New Building:—						
Contract, Extras	158	18	2			
Furniture	55	15	8	214	13	10
— Benevolent Fund Disbursements, 1871				9	6	1
— Investments:—						
Telford Fund.—Balance of Income not yet expended in Annual Premiums, Invested in £275. 17*s.*, Three per Cent. Annuities	254	9	7			
Miller Fund.—Ditto, ditto, £442. 6*s.*, Three per Cent. Annuities	408	0	4			
General Account.—£1,500, London, Brighton, and South Coast Railway, Four and a Half per Cent. Debenture Stock	1,517	0	9	2,179	10	8
— Balance of Petty Cash Dec. 1, 1871, in the hands of the Secretary				1	10	9
— Balance in the hands of the Treasurer				377	12	3
				£8,287	5	1

Examined and compared this Account with the Vouchers and the Cash Book, and find it to be correct, leaving a Balance in the hands of the Treasurer of Three Hundred and Seventy-seven Pounds, Twelve Shillings, and Threepence. —Nov. 30th, 1871.

(Signed) HUTTON VIGNOLES, } *Auditors.*
ROBT. C. MAY, }
JAMES FORREST . . *Secretary.*

December 4th, 1871.

APPENDIX TO ANNUAL REPORT.

MEMOIRS.

FIELD-MARSHAL SIR **JOHN FOX BURGOYNE**, Bart., G.C.B., &c., &c., &c., was born in Queen Street, Soho, on the 24th of July, 1782. He was the son of the Right Honourable General Burgoyne, who commanded the expedition from Canada against the United States in 1777, and who, in consequence of the orders to Sir William Howe to co-operate with the movement having miscarried, was forced to surrender with his whole army, to the Americans, at Saratoga. Sir John's godfather was Charles James Fox, from whom he took his second name. Young Burgoyne was only ten years of age at the period of his father's death, and General Burgoyne having left debts which the proceeds of his estate barely sufficed to cover, his son was left without resources to make his way in the world. Lord Derby, the great grandfather of the present Earl, and the intimate friend of General Burgoyne, however, kindly undertook the care of the orphan boy, gave him a home, and supplied means for his education. He was for some time with a private tutor, the Rev. Mr. Maule, at Cambridge, from whence he went to Eton, where he was fag to the historian Hallam. In 1796, he entered the Royal Military Academy at Woolwich; and in 1798, at the early age of sixteen, obtained his first commission as lieutenant in the Royal Engineers.

From his first entrance into the army, John Burgoyne commenced a career of active and laborious service, which continued without intermission for the extraordinary period of seventy-one years. In 1800 he embarked in the expedition under Sir Ralph Abercrombie; but was detached at Minorca, to be employed in the blockade of Malta, and was present at the capture of Valetta. He joined the army in Sicily in 1806, accompanied the expedition to Egypt, as Commanding Engineer, and served at the assault of the lines of Alexandria, and the siege of Rosetta. Sir John Moore, who was much struck with the abilities of the young officer, now applied for his services, and in 1808 he accompanied the expedition to Sweden, and went afterwards to Portugal. He was present during the retreat to Corunna, during which he blew up the bridge at Benevente, in presence of the advancing enemy, and thus checked the pursuit. In 1809, he joined the army in Portugal under the Duke of Wellington, then Sir Arthur Wellesley, and was engaged in all the great actions of the campaign, including the passage of the Douro, the affair of Salamonde, the retreat to the lines of Torres Vedras—where he blew up Fort Concepcion in the presence of the enemy, a successful operation requiring great judgment and coolness—the battle of Busaco, the first siege of Badajoz, the action of Elbodon, the action of Aldea de Ponte, the siege and capture of Ciudad Rodrigo, and the siege and capture of Badajoz. Both at Ciudad Rodrigo and at Badajoz, Burgoyne accompanied the 3rd Division in the assault, and obtained at each a step of Brevet rank. He served as Commanding Engineer at the siege and capture of the Forts of Salamanca and in the battle of Salamanca, at the capture of Madrid and the Retiro, where two thousand French troops surrendered, and at the siege of Burgos, where he was wounded. He was present during the advance in 1813, at the battle of Vittoria, where his horse was shot under him, and at the siege of San Sabastian, where he was severely wounded in the assault. He conducted the siege of the Castle of San Sebastian, as Commanding Engineer, his senior officer, Sir Richard Fletcher, having been killed in the assault upon the town; he was engaged in the action of the Bidassoa, the battles of the Nivelle and of Nive, the passage of the Adour, the blockade of Bayonne, and the repulse of the sortie. Burgoyne afterwards accompanied the expedition to New Orleans as Commanding Engineer, and served in the attack on the enemy's entrenched position, and at the capture of Fort Bowyer. On his return from New Orleans, he joined the army of occupation in Paris. At the close of the war in 1815, Lieut.-Colonel Burgoyne, then aged thirty-two, had been mentioned eight times in despatches, had received five gold medals, the cross of the Tower and Sword, and the decoration of the Bath.

During the campaign in the Peninsula, Burgoyne earned that high reputation for bravery, judgment, and unflinching adherence to duty which accompanied him throughout his long life. His coolness in danger was the admiration of all who served with him. Lieut.-Colonel Nevill, 63rd Regiment, in his relation of the siege of Burgos, says, "Colonel Burgoyne was the wonder of us all; he seemed to bear a charmed life, for he was almost ever in the trenches, mines, and lodgments;" and an anecdote is narrated of the Duke of Wellington at one of the sieges, exclaiming, "Here comes that fellow Burgoyne, bringing up all the fire after him, as usual!" Burgoyne having cut across parallels, zigzags, &c. to obey a summons of the Duke. In spite of the diffidence and retiring disposition which characterized him, Colonel Burgoyne early attracted the notice, and won the steady regard, of his commanding officers. Sir Thomas Picton, whose Division (commonly called the Fighting Division) he accompanied in most of the actions and sieges in which it took part, conceived a warm friendship for him, which was continued to the death of that distinguished officer. On finding that Burgoyne's application to accompany the army to Belgium was refused, on account of the wish of the Government of that day to give the command of the Engineers to another officer possessed of party interest, Sir Thomas earnestly applied to be allowed to take him as an aide-de-camp. This request, however, was rejected, and Burgoyne, to his great disappointment, lost the opportunity of bearing a part in the crowning fight of Waterloo.

Peace came at last, but brought no rest to the unflagging energy of Burgoyne. He then commenced a long period of Civil Service, as arduous if not as dangerous as his military campaigns. He was appointed Commanding Engineer at Chatham until 1827, when he was sent in the same capacity to Portugal with the army under Sir William Clinton. On his return, he occupied the post of Commanding Engineer at Portsmouth. In 1831, he was appointed chairman of the newly constituted Board of Public Works in Ireland, an office which he held for thirteen years. During this time he was employed on many undertakings of great public utility. He acted as chairman of a commission for the improvement of the navigation of the Shannon, on which elaborate reports were made, and published among the Parliamentary Papers; and subsequently the proposed works of great extent were carried out by the same Commissioners. He was a member of the Commission appointed in 1836 "to consider and recommend a general system of Railways for Ireland," of which Mr. Thomas Drummond, then Under Secretary of State for Ireland, was President, and Mr. Peter Barlow, Hon. M. Inst. C.E. and Sir Richard Griffith, Bart., M. Inst. C.E. (then Mr. Griffith) were members, and the late General Sir Harry Jones, M. Inst. C.E., was the Secretary. The Commissioners entered into a number of investigations, and drew up a report[1] of much interest. A great portion of this report was written by Colonel Burgoyne, and it is now admitted that had the advice therein given been followed, the present embarrassments on the subject of Irish railways might in a great degree have been avoided. Both in framing this report, and in his subsequent endeavours to establish a system of State Railways for Ireland, Colonel Burgoyne derived material assistance from the labours of Mr. Charles Vignoles (late President Inst. C.E.). Colonel Burgoyne was also Chairman of Commissioners of Drainage, Member of the Board of the Wide Streets Commissioners for Dublin, and chief Commissioner of Kingstown and Dunmore Harbours. While fulfilling these duties in Ireland, Colonel Burgoyne was requested by the Master-General of the Ordnance to report upon a matter which had been under discussion for some years, relative to giving up an old battery at Liverpool, which impeded the construction of new docks there. His report adjusted the dispute, and he submitted plans for a new battery, which was subsequently constructed. For this service he received a complimentary letter from the Master-General and Board of Ordnance.

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[1] *Vide* "Second Report of the Commissioners appointed to Consider and Recommend a General System of Railways for Ireland." Folio. Dublin, 1838.

Colonel Burgoyne was one of the founders and the first President of the Institution of Civil Engineers of Ireland, and delivered the inaugural address on the 6th August, 1835. In 1838, he was promoted to the rank of Major-General, and was made a Knight Commander of the Order of the Bath. On the 12th of February, 1839, Sir John Burgoyne was elected an Honorary Member of THE INSTITUTION OF CIVIL ENGINEERS. The letter announcing his election states that "the Council and Institution felt such a tribute of respect to be most justly due to his eminent acquaintance with the public works of a sister country, and to the interest taken by him in the pursuits of the Civil Engineer."

Mr. Rowland Hill's project for a cheap postage was taken into consideration in 1838. Burgoyne took the deepest interest in the plan, and did all in his power to insure its success. The energy and perseverance with which he prosecuted inquiries into every subject which he believed might be conducive to the public benefit, were well exhibited in his exertions on this occasion. In a letter from Mr. George Moffatt, M.P., one of the warmest partisans of the scheme, that gentleman thanks him for a Paper, "the result of a series of elaborate calculations, and practical observations upon the change in the existing system of postage taxation," which Paper was transmitted to the Chancellor of the Exchequer. Burgoyne strongly advocated the immediate reduction of the charge upon letters to a penny, instead of the tentative measure of a twopenny postage which was at first proposed.

In 1845, Sir John Burgoyne received a letter from Sir George Murray, Master-General of the Ordnance, offering him the post of Inspector-General of Fortifications, and assuring him that his appointment to that office would be popular in the whole corps of Royal Engineers, at whose head he would thus be placed. He accordingly resigned his appointment at the Board of Works and left Ireland, followed by the regret of all who had been associated with him there, in either a public or a private capacity. An address from the Institution of Civil Engineers of Ireland was presented to him at the time of his departure, accompanied by the following letter:—

"SIR,

"I have the honour to inform you that at a recent meeting of the Institution, it was unanimously resolved, That an Address should be presented to you from the President and Members, expressive of their deep regret at your departure from this country, and your consequent resignation of the Presidentship of the Institution, and I now beg to forward to you this Address.

"I have also the honour to inform you that, by direction of the Council, you have been transferred from the class of Ordinary to that of Honorary Member of the Institution. I feel peculiar pleasure in being the means of conveying to you this Address, expressive of those feelings in which I am aware every Member of the profession unites, towards one who so jealously guarded its best interests in this country.

"I have the honour to be,
"Sir,
"Your most obedient Servant,
"T. OLDHAM,
"*Secretary.*"

One of Sir John Burgoyne's first acts, on assuming the post of Inspector-General of Fortifications, was to draw up a letter to the Master-General of the Ordnance, containing an exhaustive statement of the deficient means of protecting the country against foreign invasion. This communication elicited from the Duke of Wellington his celebrated letter, the publication of which first awakened the country to a full sense of its defenceless state, and strengthened the Government in their measures to guard against the disasters which must have eventually ensued from such long continued neglect. Soon after Sir John Burgoyne's establishment in his new position, his services were called upon for an undertaking most difficult and unprecedented, namely, that of organizing and directing the operations of a Relief Fund for the distress in Ireland, caused by the famine in 1847. In the Treasury letter relating to Sir John's appointment, it is stated that his "intimate knowledge of Ireland, and the confidence with which he is regarded in that country, have induced Her Majesty's Government to select him to be the head of a temporary Commission about to be appointed for the adoption of further measures for the relief of the distress arising from the scarcity." Mr. Labouchere, then Secretary for Ireland, said in a letter he addressed to Sir John at that time, "I am sure that your assistance to the Lord Lieutenant at this juncture will be productive of the best results, and your name will inspire more confidence and respect than that of any other man who could have been selected for the difficult task you have undertaken. I assure you that in common with every other member of the Government, I am fully sensible of the obligations which both the country and we are under to you for the sacrifice of personal comfort which you have made for the public good." It is unnecessary here to enter into any details of this gigantic undertaking. It was universally admitted to have been completely successful, and the Government openly acknowledged that for the main part of that success, they were indebted to the judgment and exertions of Sir John Burgoyne.

On his return to England he was employed on many Commissions on various subjects connected with the public service. Thus, in 1848, he was appointed with Lord De Grey and Mr. Thomas Greene, M.P., Royal Commissioners, to superintend the completion of the new Palace of Westminster. In 1849, he was requested to proceed to Inverness, for the purpose of inquiring into the state of the Caledonian Canal, and into the causes of the inundations by which the town of Inverness had suffered considerable injury. Upon this subject he made a comprehensive report, which has been deservedly praised by many eminent Civil Engineers. The next subject of public interest on which he was engaged was old Westminster Bridge, on the state of which he made a report, at the desire of the Chancellor of the Exchequer, who was at the head of a Commission, consisting of no less than ninety-eight members, for the management of the affairs of the bridge. In this report, dated September 1849, Sir John gave a decided opinion that any attempt to prolong the period before an entire reconstruction would be hopeless without an utter waste of large sums of money; and he recommended that a temporary bridge should be at once constructed, the old structure be entirely removed, and operations for a new bridge be proceeded with uninterruptedly. His conclusions were ultimately adopted by the Government, and the present structure was the result. The Royal Commission on the Transatlantic Packet Stations was constituted in 1850, and Sir John was appointed one of its members, the others being Earl Granville, the Hon. William Cowper, M.P., Admiral Sir James Gordon, and Captain Ellerby. He was also a member of the Commission on Army Promotion, and served on confidential Committees nominated to investigate and report upon Lord Dundonald's, Captain Warner's, and other inventions, supposed to be of importance to the military service. When the first Commission of Metropolitan Sewers was instituted, Sir John Burgoyne was nominated one of the original members, and on its expiration in 1852, he was re-appointed to serve on the second Commission. At the Great Exhibition of 1851, Sir John was Deputy Chairman of the Jury for Class VIII., of which Baron Dupin was Chairman. About this time he became associated with a Society to promote an object in which he always felt deep interest; that of obtaining a cheap and uniform system of International Postage. He was also employed on many secret Committees and Inquiries, on most of which he addressed reports to the Government, which produced more or less important results.

In 1854 the peace of Europe became endangered by the menacing attitude of Russia towards Turkey, and Sir John Burgoyne was despatched to the East by the Government, to consider the best means for the defence of Constantinople and the Dardanelles, against an advance by the Russians. There was at that time no idea of sending out large forces from France and England, and Sir John's plans were consequently limited to the construction of defensive lines at the Dardanelles and the Bosphorus, which would enable the Turks, with the aid of an Allied Fleet, to protect themselves against an attack. The Governments of the Allied Powers, however, afterwards resolved upon bolder and more extensive measures, and it has always been understood that Sir John Burgoyne's representations to the Emperor Napoleon had much effect in determining him to send out large forces to the scene of action. When the expedition to the Crimea was decided upon, the Government wished to afford Lord Raglan the assistance of one whose military skill and experience was well known. The Duke of Newcastle sent for Sir John Burgoyne, and, after ascertaining that he was willing to undertake the duty assigned to him, inquired how soon he would be ready to set out? "In twenty-four hours," replied Sir John; and in that space of time he made all his preparations, and left England for Turkey. For a man of seventy-two years of age, this must be regarded as an extraordinary act of vigour and energy; but Sir John's excellent constitution and equable temper had prevented the weight of years from pressing upon him. At the age of seventy, he was actually younger than many men of fifty. He was wont to observe that when at school his playmates used to call him *old* Burgoyne, while now that he was advanced in years he became generally known as *young* Burgoyne. The operations in the Crimea are of too recent date to require much repetition. It was to Sir John Burgoyne that many of the most important steps of the campaign were due. He recommended the spot where the landing of the troops eventually took place; he originated the celebrated flank march; and he fixed upon the Malakoff as the key of the position, and strenuously urged that the attack should be directed upon that point. His iron frame appeared incapable of injury by hardship or fatigue. He rode by Lord Raglan's side through the battle of the Alma, accompanied him in the subsequent long march, and slept on the ground in the open air, like the youngest soldier of the army. When the disasters of the winter caused great public discontent in England, and the years of the commanding officers became numbered against them as so many crimes, the Government gave way to the popular clamour, and recalled Sir John Burgoyne. Sir John felt this deeply as a slur upon his military reputation, yet he never uttered a word of complaint; and when examined before the Sebastopol Committee, shortly after returning to England, he did not allow any sense of injustice to influence his evidence, or to draw from him any disclosures or opinions which might prove injurious to the Government which had sacrificed him. The fall of Sebastopol, in September 1855, by a successful attack on the Malakoff Tower, proved the wisdom of Sir John's counsels, and vindicated his military judgment. The Government created him a Baronet, the notification of the Queen's pleasure being conveyed to him in a very complimentary letter from Lord Panmure, Secretary of State for War, stating that the distinction was granted to him for his "long and faithful service to the Crown, which had lately been attended with such important results in the Crimea." He was now promoted to the rank of full General, the commission being antedated, so as to place him in his proper station above those officers who had passed over his head since his return from the seat of war. He also received the thanks of both Houses of Parliament.

Shortly afterwards Sir John was appointed a member of the

Defence Committee, on which he continued to serve until his death, and of the Commission for the distribution of the Patriotic Fund. He was likewise one of the Jurors of the Great International Exhibitions of 1855 and 1862. He took great interest in the formation and subsequent welfare of the "Engineer and Railway Volunteer Staff Corps," from which he anticipated important results in the organization of railways for the conveyance of troops, and he frequently, both in speaking and writing, expressed his appreciation of the merit and value of that corps of which he became an Honorary Member. In a letter to Lieut.-Colonel Manby, Acting Adjutant, Sir John says,—"It is a corps certainly calculated to render very eminent services, and I shall never cease to take a deep interest in it and its objects."

After the disastrous explosion of a store-magazine at Erith in 1864, a Committee was appointed to inquire into the state of the Military and War Department Magazines. Of this Sir John Burgoyne was President. The report, which was a very able document, was drawn up by him, and has become the text-book by which the storage of gunpowder is regulated in the public service, all the recommendations having been adopted by the Secretary of State for War. Sir John was afterwards employed as a member of a Committee on the Concentration of the Public Offices.

In 1865, the dignity was conferred upon him of Constable of the Tower of London and Lord Lieutenant of the Tower Hamlets. Sir John was the first Commoner who had held that office since the feudal era, and he greatly prized the appointment. The distinction, however, was purely honorary, the salary, originally £1000, being discontinued after the death of Lord Combermere, Sir John's immediate predecessor. In 1868, Sir John Burgoyne retired from the office of Inspector-General of Engineers. In consideration of his long services, extending without intermission over a period of seventy-one years, he was allowed to retain the full salary of the office he last held, and he was promoted to the rank of Field-Marshal. But Sir John's labours did not cease on his retirement from office. He was still a member of various Committees and Commissions which he regularly attended. His advice was sought on several important military questions, and he wrote articles in newspapers and magazines on most of the military topics of the day. His interest on every point which affected the public good was as great as ever; his opinions and counsels appeared at last to be appreciated at their full worth, and there was every appearance of his passing many years peacefully with

> "All that should accompany old age,
> As honour, love, obedience, troops of friends;"

when a heavy blow fell upon him which shattered even his iron constitution, and "brought his grey hairs in sorrow to the grave." Sir John's life was bound up in his affections, much of which was centred in his only son, Captain Hugh Burgoyne, of the Royal Navy, who had early distinguished himself in the sister service, and who promised to cast fresh lustre on his father's name. Captain Burgoyne was devoted to his profession; he had served with great credit to himself in the Sea of Azof; he had gained an early promotion to the rank of Post-Captain, and he was one of the original recipients of the Victoria Cross. In the spring of 1870, he had been selected to take command of the new turret ship, the "Captain," the great experiment of the day, and one which there was every reason to suppose would prove completely successful. The "Captain" had already gone through one trial trip, had safely weathered a heavy gale of wind, and had given satisfaction to her commander and to all on board. In August, 1870, she sailed on another expedition with the Channel Fleet. On the 14th of September she was expected home; but on the 9th of that month the startling news arrived, that she had capsized on the 7th, in a gale of wind through which every other ship in the fleet had ridden in safety. All on board perished with the exception of nineteen sailors who escaped in one of the boats, and who were able to give melancholy details of the last moments of the captain of the ill-fated vessel. Sir John Burgoyne bore the sad news with the fortitude and resignation which he always showed under calamity; but the shock was overpowering to a man of eighty-eight, and from that moment he became a broken down invalid. From time to time, during the ensuing year, he rallied in some degree, but the spring of life was broken. Although incapable of bodily exertion, his intellect remained bright and unclouded to the last. He still took occasional interest in public affairs, and in the summer of 1871, when the debates in the House of Commons on the new Army Bill were taking place, he wrote a letter to "The Times" on Army Promotion, which attracted much notice, and was often quoted in both Houses of Parliament. This was, however, his last effort. His strength declined so gradually that until the very morning of his death his family had no idea of any immediate danger, and on the 7th of October, 1871, he expired without a pang or struggle, surrounded by those he loved, and smiling upon them to the last.

Many public men have been more admired, but none have been more generally beloved, than Sir John Burgoyne. His kind and gentle manner, his benevolence, and his utter unselfishness, won the affection of all who became associated with him. No one ever applied to him for assistance without receiving kind sympathy, and as much aid as it was in his power to bestow. He was remarkable for his fondness for children and animals, and an act of cruelty to one or the other was the only thing that had power to ruffle his temper. Even at his great age, he retained all his sympathies with the young, and was ever forward in promoting their pleasures and amusements. The feeling commonly known by the term *esprit de corps* was a distinguishing characteristic in him. Next to his family, he loved and felt pride in his own corps, and never let an opportunity pass of promoting their welfare, whether individually or collectively. His modest and unassuming character was a drawback to his advancement through life. The Duke of Wellington understood him well when he said, " If Burgoyne only knew his own worth, there would be no one equal to him." He always thought it natural to see others preferred before himself, and never refused his assistance and advice, even when placed in a subordinate position where he had a right to hold the chief place. But with all his gentleness of disposition, the sterner qualities which command success in life were not wanting in him. He possessed in an eminent degree that high form of moral courage which never fails in moments of difficulty or danger, and he was always ready to assume the responsibility of actions entailing a possibility of disaster as well as of success; nor did he ever shrink from taking the responsibility of a failure upon himself. The slightest deviation from truth, or anything approaching to a subterfuge, was impossible to him. His firmness of character was remarkable: he was ever ready to listen to the arguments of an opponent, and his mind being free from prejudice, was always open to conviction; but having once resolved on the right course to pursue, no power could induce him to depart from it. His character cannot be better summed up than in the words of the Venerable G. R. Gleig, in the funeral sermon preached by him in St. James's Church on the 22nd October. He then spoke of his old friend as " one whose long career, extending over " a wider space than the allotted life of man, was without a spot " to which the finger of malice could point, or the most hostile " critic hold up to public censure. It was almost impossible to " converse with him without deriving benefit. Controversy or " disputation were odious to him: even in pointing out to a man " that he was wrong in argument, he did it so as not to lower

" him in his own estimation. He was a religious man, but his " religion was of a simple unpretending kind, looking for salvation only through the merits of his Saviour. His generous " heart will beat no more; his pure spirit has gone back to Him " who gave it, but he has carried to his resting-place in the " Tower the affectionate reverence of his countrymen and the " admiration of the world."

SIR JOHN FREDERICK WILLIAM HERSCHEL, Bart., K.H., D.C.L., F.R.S., &c., the only son of Sir William Herschel, the discoverer of the planet Uranus, was born at Slough on the 7th of March, 1792. He received his early education privately, under a Scotch mathematician named Rogers, and subsequently entered St. John's College, Cambridge, where he took his B.A. degree in 1813, coming out as Senior Wrangler and first Smith's Prizeman. In the same year he published his first work, " A Collection of Examples of the Application of the Calculus to Finite Difference." In 1819 he commenced a series of Papers, in the " Edinburgh Philosophical Journal," on miscellaneous subjects in physical science; and in 1822 communicated to the Royal Society of Edinburgh a Paper on the absorption of light by coloured media. In 1816 he began to examine the double stars, in continuation of his father's work, Sir James South being united with him in the undertaking from March, 1821. The results appeared in six Memoirs, the last of which was published in 1836. His catalogue (made at Slough) of nebulæ and clusters of stars is contained in the Philosophical Transactions of the Royal Society for 1833. Early in 1834 he removed with his family and instruments to the Cape of Good Hope, where he remained for four years, for the purpose of observing and cataloguing the double stars and nebulæ of the southern hemisphere. The results were published, in one volume, by the munificent aid of the Duke of Northumberland, in 1847, and his general catalogue of nebulæ appeared in the Transactions of the Royal Society for 1864. On his return from the Cape, in May, 1838, he was made a baronet; and from December, 1850, to February, 1855, he occupied the post of Master of the Mint. The latter part of his lifetime was spent at Collingwood, near Hawkhurst, Kent, where he died on the 11th May, 1871. One who knew him well writes that he was " an excellent workman, and his lathe-room adjoining his laboratory and his study was in constant use. . . . He made a working model of all his contrivances; and this as much from a determination to work up from the beginning of everything, and to meet and conquer every difficulty of construction himself, as from any mere love of manual work. . . . The system of the revolving roof on balls for his equatorial telescope was his own contrivance, and the whole building was made at Slough under his directions, and was capable of being taken to pieces and re-erected at the Cape. The ingenuity needed, and absolutely necessary, in contriving some support for the heavy metal mirror of the 20-feet telescope, so that its figure should not be distorted, always excited our great admiration. . . . In such powers of contrivance, and in the mechanical knowledge which aided his ingenuity, no one would pretend that Sir John was pre-eminent, but that these should be found joined in the mind of the thoughtful philosopher, who threw his penetrating glance into every region of human speculation, lighting a beacon in advance here and there . . . ought to teach us, that the truly great mind is a well-balanced one. His private life and his study table were as garden ground to his roots, but his branches and his fruit he gave largely and ungrudgingly to the public; and the affectionate respect which greeted him wherever he went returned as light and air to his very heart, nourishing and increasing the wise and generous patriotism of his nature. . . there was nothing behind, to conceal or to reveal. Had it been in human nature to harmonise perfectly the aspirations and the actions of life, he would have done it—assuredly he attempted it." A more detailed account of Sir John Herschel's life is given in the Proceedings of the Royal[1] and of the Royal Astronomical Societies, and in the "Athenæum" and "Nature."[2] It may suffice to add that he was elected an Honorary Member of the Institution of Civil Engineers on the 26th of June, 1838; and that in 1829 he married Margaret Brodie, daughter of the Rev. Dr. Alexander Stewart, of Strathgarry, Perthshire, by whom he had a family of three sons and nine daughters.

MR. JOSEPH HAMILTON BEATTIE, the son of Mr. George Beattie, an architect and builder in the north of Ireland, was born on the 12th of May, 1808. He served an apprenticeship under his father, and for several years was engaged in the same business. In 1835 he left Ireland, and obtained employment under Mr. Joseph Locke, Past-President Inst. C.E., at first as an assistant engineer on the Grand Junction railway, and in 1837 on the London and Southampton, now the London and South Western railway, and he superintended the construction of a large portion of the buildings and the laying of the permanent way. Subsequently he was entrusted, in addition, with the charge of the carriage and wagon stock of the line, and in 1851 he was also appointed locomotive superintendent, and these joint offices he retained till his death. Mr. Beattie took out many patents for improvements in railway rolling stock, which have resulted in increased efficiency, safety, and economy of working. His first patent, in 1840, included a contrivance for enabling an increased proportion of the weight of a locomotive engine to be temporarily placed upon the driving-wheels when necessary; also improved construction of buffing-springs, breaks, and signalling apparatus between guard and engine-driver, couplings, chairs, wooden railway wheels, and a duplex lathe, by which two wheels can be turned at the same time. Other patents followed, relating to the construction of permanent way, apparatus for heating the feed water of locomotive engines, fire-boxes for burning a mixture of coal and coke, and for burning coal instead of coke, oil axle-boxes for engines and carriages, axles, tires, modes of attaching the tire to the wheel, safety guide rails to be used on sharp curves, and an arrangement of perforated piping to be connected with the water-mains for extinguishing fires in buildings and warehouses, which was afterwards applied to the shops at Nine Elms in which the painting and repairing of railway carriages are carried on. But it was for the economies he effected in the consumption of fuel in working locomotives that he obtained the most repute. So far back as 1851 he noticed the waste of fuel in the process of manufacturing coke for locomotives, and found that a third of the weight of the coal was lost, and passed off as smoke. It was afterwards shown in practice, that coal possessed an evaporative power equal to coke, and was not so destructive in its action on the tubes of the boilers. However, it was necessary to consume the smoke evolved, both to avoid the nuisance and to obtain the full evaporative power of the fuel, and to this problem Mr. Beattie, among other railway engineers, for some time gave his almost undivided attention. The earlier coal-burning engines were constructed with fire-boxes considerably larger than the coke-burning fire-boxes; they were divided transversely into a front and back furnace, and had also a combustion chamber partly filled with perforated fire-bricks in the barrel of the boiler: but in later engines, Mr. Beattie found that almost equally good results were obtainable by using a still larger fire-box without the combustion-chamber. By another arrangement he utilized a portion of the waste steam for heating the feed-water to a temperature of nearly 212° Fahrenheit, and in that way saved about 13½ per cent. of the fuel formerly used. These measures effected a saving of £30,000 a-year on the London and South Western railway, where the system is adopted to its full extent; and the improvements introduced by Mr. Beattie were so generally adopted, that he realized a large fortune. In 1863–4 he designed the arrangement of the new workshops, and the machinery for the use of the locomotive and carriage department, of the London and South Western railway, at Nine Elms. He was elected a Member of the Institution of Civil Engineers on the 1st of December, 1857, but he was not a frequent attendant at the meetings. He died on the 18th of October, 1871, from inflammation of the lungs, after an illness of three weeks, leaving a wife and three sons, the second of whom succeeded him as locomotive engineer to the London and South Western Railway Company.

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[1] *Vide* vol. xx., p. xvii.

[2] *Vide* vol. iv., p. 69.

MR. JOHN GEORGE BLACKBURNE was born in London, on the 4th of June, 1815; but his father, who was a Lancashire man, removed back to his native county, and sent his son to school at Worksop. The scanty means of the father necessitated the son's early application to business; so Mr. Blackburne was articled on the 31st of May, 1828, for seven years, to Mr. William Dunn, then practising as a land and mining surveyor in Oldham, and in whose office Mr. J. F. Bateman, M. Inst. C.E., F.R.S., was at the same time a pupil. On the 5th of June, 1835, Mr. Blackburne became Mr. Dunn's partner; this connection was dissolved by the death of Mr. Dunn on the 27th of June, 1840. By this time Mr. Blackburne had exhibited such an aptitude for business, that he was largely employed as a surveyor in promoting or opposing schemes for railways in South Wales and Lancashire. During the railway mania of 1844–6 he was employed, under Mr. Hawkshaw, Past-President Inst. C.E., in surveying and laying out a system of railways which was to place Oldham in direct communication with Manchester, Ashton-under-Lyne, Rochdale, and Saddleworth. The Act was obtained, but a change in the aspect of things rendered the abandonment of the undertaking necessary. It was not until twenty years after these lines were laid out, that Mr. Blackburne had the satisfaction of seeing the whole network completed. In 1853, he designed and superintended the erection of the Dukinfield New Bridge, which rendered the road from Ashton to Dukinfield more convenient and easy, as well as shorter. Some years previously he had had charge of the Spotland Reservoirs, near Rochdale, as well as the superintendence of all new street works and sewerage for the Borough of Oldham. This latter duty he continued to perform until the appointment of a borough surveyor in 1863. In 1854-5, he acted as surveyor for the new Oldham Waterworks at Piethorn, of which Mr. Bateman was the consulting engineer, and Mr. George Emmott the resident engineer. In 1858, he laid out the Oldham, Ashton, and Guide Bridge railway (5½ miles), and superintended its construction, as well as at the same time having charge of the works on the Hyde and Marple railway (4½ miles). In 1859, he laid out the Marple, New Mills, and Hayfield railway (6½ miles), and the Stockport and Woodley railway (3 miles); and afterwards acted as engineer for the execution of both lines. The heaviest works on these railways were the Park bridge, the Marple and the Goyte Cliff viaducts, the former of which was entirely of masonry, comprising ten spans of 50 feet each, and 90 feet in height, while the Marple viaduct consisted of thirteen stone arches of 50 feet span, and a height of 120 feet, with an iron lattice girder bridge over the Peak Forest canal, having opening of 87 feet; and the Goyte Cliff viaduct has seven spans of masonry, also of 50 feet, and a height of 85 feet, with an iron plate girder bridge over the river, having an opening of 82 feet. The only other feature on the whole of the works was the prevalence of laminated clay, which rendered the cuttings and embankments very troublesome, and the cost of construction proportionately great.

In 1862, Mr. Blackburne made his son, Mr. John William Blackburne, M. Inst. C.E., his partner. In 1864, he and Mr. Emmott were appointed engineers to the Ashton and Stalybridge (Corporations) Waterworks, which scheme was, after a severe contest, got safely through both Houses of Parliament. These works (now nearly completed) were for some time under the joint superintendence of Mr. Blackburne and Mr. Emmott, until the latter gentleman resigned his responsibility on account of failing health. In 1865, Lord Howard of Glossop applied for powers to construct waterworks for the supply of Glossop, and his lordship entrusted the Parliamentary scheme, and subsequent execution of the undertaking, to Mr. Blackburne. In 1868, he was consulted by the Oldham Corporation, as to the best way of obtaining an additional supply of water for that town. He reported upon two schemes, viz., Denshaw and Greenfield. The Corporation decided upon applying for the latter as the largest and best, but, although a strong case was made out, the Committee of the House of Commons decided that the towns of Ashton, Stalybridge, and Dukinfield, had a prior claim on that gathering ground. This expression of opinion led the authorities of those towns to seek for the necessary powers, which were obtained in the following year, when Mr. Bateman acted as engineer to the scheme, the main features of which closely resembled Mr. Blackburne's. In 1869 the Oldham Corporation, acknowledging the absolute necessity for an extra water supply, ordered plans to be prepared for reservoirs at Denshaw, and an extension of their existing works at Piethorn. Mr. Blackburne was appointed engineer to the undertaking, and had been actively making arrangements for the vigorous execution of the works when he died.

In 1855 he was admitted a Member of The Institution of Civil Engineers, and in the same year he became a Fellow of the Geological Society, and in 1866, a Member of the Manchester District Society of Surveyors and Valuers. He was the first President of the latter Society, and was, at the time of his death, the Treasurer of it. From 1853 to 1871 he was constantly engaged on Parliamentary business, as his clear-headedness and thorough knowledge of all branches of the profession rendered him a good witness, and thus either a great support or an awkward adversary. For many years he had been an authority on mining cases in Lancashire, where his name "had become a household word." He also enjoyed a large practice as witness, arbitrator, or umpire in disputed compensation, water-right, and other similar cases; for in no branch was he more highly trusted and esteemed for his honesty of purpose and straightforward conduct. Besides being so fully immersed in the calls of his profession, he took an active interest in the educational and other kindred institutions of Oldham, and was for nearly twelve years in command of the 31st Lancashire Rifle Volunteers, having, at the time of his death, reached the rank of Lieut.-Colonel.

In June, 1870, he had a threatened attack of paralysis, having suffered for years greatly from pain in the head; and the doctors strongly advocated a complete withdrawal from business. This advice was to a great extent acted upon for some months, and as a relaxation, he attended the Wellington Barracks in London, in February, 1871, for the purpose of obtaining his certificate of proficiency. With the return of health, however, came back that strong desire for active occupation of mind and body that had ever distinguished him, and which had obtained for him a reputation which will long survive. Towards the end of August he again complained of pain in the head, and on the 28th of September, whilst viewing some property near home, he was seized with dizziness. The doctor was sent for and advised rest; but in the afternoon of the following day Mr. Blackburne had a paralytic stroke, followed by an attack of apoplexy, which terminated fatally on the 30th of September, 1871.

MR. FREDERIK WILLEM CONRAD was born at Spaarndam near Haarlem, in the year 1800. He was the youngest son of Mr. F. W. Conrad, Inspector-General of the Waterstaat in Holland, whose name is honourably associated with several important works, executed in the beginning of this century, and especially with the large sluice works near Katwyk. After having followed a course of study at the engineering school at Delft, Frederik Willem Conrad entered, at the age of seventeen, the corps of the Waterstaat; and passing successively through the different ranks, he was promoted in 1866 to the high position which was held some years before by his father.

It was only after long years of political disturbance, that the Treaty of Vienna secured the independence of the Netherlands in 1815. The revival of national prosperity soon enabled the Government to order the execution of large public works, that were required for the development of trade and industry. In the designing and execution of these works Mr. Conrad took a very active part. After having distinguished himself, in 1820, in repairing the damage, caused by serious inundations, he was called upon, in 1822, to undertake the construction of a dock at Hellevoetsluis, and in 1824-25 he made the Zederik canal, between the Leck at Vianen and the Merwede at Gorcum. In 1828 the Dutch Academy of Science awarded him a gold medal for a Paper upon the best methods of preventing the sinking and sliding of earth embankments. During subsequent years, Mr. Conrad, in his Waterstaat Service, was engaged upon important river works, especially along the shores of the island of Goerée, and in making designs for several canals. He also contributed to the first designs for the drainage of the lake called Haarlemmermeer.

In March, 1839, Mr. Conrad entered upon the duties of Engineer Director of the Railway Company of Holland, to which position he had been appointed by the Government, at the request of the Council of Administration of the Company. He at once took in hand the laying out of the railroad from Amsterdam to Rotterdam, which had been commenced in 1838, and in the construction of which he gave proof of great engineering abilities. The difficulties offered by the weak peat soil were successfully overcome, by the use of fascines in marshy spots as a foundation for the embankments, which were chiefly composed of sand from the sea beach; and where the railway traversed pools of water, the fascines were loaded with rubble stone, and were held together by stakes and wattles. The works of art embraced several descriptions of swing and other opening bridges, including one called the "turn-rail" bridge, which was specially devised by Mr. Conrad as a cheap and simple mode of crossing the numerous canals intersected by the line of railway. Each rail was carried on a timber bearer, jointed to a heel part of oak, which was shod with iron and turned upon a centre, on a plate set in the masonry of the abutments. The bearers were further supported by brackets of cast iron, and each pair was connected by two bars, turning as joints, to preserve the parallelism of the rails, and each pair opened outwards. This form of bridge was found to answer well for spans not exceeding 16 feet. These and other peculiarities in the construction of this the first Dutch railway secured him a great reputation. He presented to the Institution of Civil Engineers an account of this railway and of the works upon it,[1] and for this communication a Walker Premium was awarded. In 1847 he gave to the Institution a description of the bridge over the Poldevaart, on the same line of railway,[2] including a sketch of the precautions necessary in preparing the foundations, on account of the treacherous nature of the ground. In 1842 he had forwarded to the Institution a history of the canal of Katwyk (before mentioned), and detailed notices of the sluices at that place;[3] and a Telford medal was awarded to him for this memoir, which he was induced to undertake by the subject being one of those proposed by the Institution, and by a desire to do justice to the memory of his father, whose early decease alone prevented him from becoming as extensively known as his talents deserved. These several communications were written in the French language, and were translated into English by Mr. Charles Manby, M. Inst. C.E., then Secretary, now the Honorary Secretary of the Institution. Mr. Conrad was elected a Member of the Institution on the 7th of March, 1843, and always continued to take a deep interest in the proceedings. In 1851 Mr. Conrad, and his friend, Mr. Outshoorn, the Architect, prepared a design for a building for the International Exhibition in Hyde Park; and he served as a member of the Jury in Class VII.,

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., pp. 173–196.
[2] *Ibid.*, vol. vi., p. 149–157.
[3] *Ibid.*, vol. ii. (1842), pp. 172–176.

"Civil Engineering, Architectural, and Building Contrivances." He was promoted to the rank of Chief Engineer of the Waterstaat in 1852, and became a member of the Committee of Government Surveyors for the drainage works at the Haarlemmermeer, which were then in course of execution under the superintendence of Messrs. Kook and Beyerinck. This committee finished its labours six years later, when the great enterprise was completed with perfect success. During that time Mr. Conrad was elected a member of the Council of the Province of South Holland, and in that position he was able to promote the execution of valuable public works.

In the year 1855 M. Ferdinand de Lesseps, acting for H. H. the late Said Pacha, Viceroy of Egypt, invited Mr. Conrad to become a member of an International Commission, for the purpose of considering and reporting on the practicability of forming a ship canal through the Isthmus of Suez, between the Mediterranean and the Red Seas, and the best mode of constructing it. This Commission was composed of the following members, in addition to Mr. Conrad, viz., Captain Harris, Captain Jaurès, M. Lentze, M. Liéussou, Mr. J. R. McClean, Mr. Charles Manby, M. Montesino, M. de Négrelli, M. Paléocapa, M. Rénaud, Mr. J. M. Rendel, and M. Rigault de Genouilly. Mr. Conrad was elected President, and shortly afterwards he became the representative, or Commissioner for the Viceroy in the Society that undertook the execution of the colossal work. In 1856 Mr. Conrad was nominated a member of the Committee of Superintendence for the construction of new dock works at Nieuwediep. In making the foundations of these works great difficulties were encountered, which were however overcome. He was also a member of the Council of the Waterstaat for the new canal from Amsterdam, and for the river-works from Rotterdam to the North Sea, which are still in course of construction, under the direction of Mr. Hawkshaw, Past-President, Inst. C.E., and Mr. J. Dirks, of Holland. As President of the Committee, appointed by the Minister, to report upon the protection of the sea-shores in the province of Zeeland, he had an important share in that interesting inquiry.

Among his many valuable papers and reports upon subjects in relation to the Dutch Waterstaat, a memoir, written in 1861, in conjunction with Messrs. Van der Kun and Fynje, upon the actual state of the rivers in Holland, deserves special mention. In that document it is shown to be necessary to continue the regulation of the river-beds, after the plan adopted by the Government, and designed by Messrs. Ferrand and Van der Kan, in 1850.

In 1863 the Danish Government asked Mr. Conrad's advice respecting canal works, which were proposed to be made for connecting the East Sea and the North Sea through Holsteÿn; and again in 1868 he was called upon to report upon different designs for a harbour on the coast of Jutland, in connection with a canal between the Liimfjord and the sea. The Free-town of Hamburg invited him and the Dutch Chief Engineer, Beyerinck, in 1864, to prepare a design for the drainage of the suburb of Hammerbrock. In 1866 the new railway works, that are still in course of construction in the province of Zeeland, met with a strong opposition in Belgium. The Belgian engineers were afraid that the railway embankments, into two open arms of the sea, called the Eastern Schelde and the Sloe, would have a bad influence upon the bed of the river between Antwerp and the North Sea. This opinion was quite opposed to that held by the Dutch engineers. A joint commission of Belgian and Dutch engineers was therefore called together, but failed in coming to any agreement upon this important question. In consequence of steps taken by the Belgian Government, three foreign engineers, Sir Charles A. Hartley, Messrs. Gosselin, and Hagen, gave each a separate report upon the subject. These three reports contained very divergent opinions. Mr. Conrad, after having studied and compared the several reports, still retained the opinion held by the Dutch engineers, and ended his report by stating, that there was no reason for the Dutch government to alter their views or designs. Since that time the works have been made, and the result is generally known to have fully proved the correctness of Mr. Conrad's opinions.

The desire to be present at the opening of the Suez canal in 1869, induced Mr. Conrad to undertake once more a journey to Egypt, to witness the completion of the great enterprise, in the accomplishment of which he had been so actively engaged. His health having been on the decline for some time, the fatigues of the return journey unfortunately proved too much for his active spirit, which had been unduly tried by his great and unceasing labours. Upon arriving at Munich on the 1st of February, 1869, he was taken ill and shortly expired. The sudden news of his decease caused a great and general feeling of mourning in his own country, and among his many friends abroad. Mr. Conrad was a man of a warm and genial nature. His witty discourse and great tact were highly appreciated among his friends. The Dutch engineers are much indebted to his continued efforts to promote a genial relation among them, and especially to his powerful impulse in the formation of a Dutch Royal Institute of Engineers. He was elected a President of the Institute in 1848, and acted in that capacity for many years. Not only the Transactions of that Institute, but also several literary and technical papers and reviews give proof of his great and manifold attainments. He was a member of several scientific bodies in England, Holland, and France. The King of the Netherlands created him a Commander in the Order of the Dutch Lion, and of that of Crown of Oak of Luxembourg. The Emperor of France, the King of Sweden and Norway, and the King of Denmark, likewise presented him with decorations. Mr. Conrad also enjoyed this great source of satisfaction, that his merits were fully appreciated during his lifetime.

MR. ROBERT BENSON DOCKRAY, the third son of Mr. David Dockray, at one time a mill-owner and manufacturer near Manchester, was born on the 13th of November, 1811. His mother's maiden name was Benson; his parents belonged to the Society of Friends, and he was educated at Friends' schools, first at Kendal, and subsequently at Darlington; but in 1847 he became a member of the Church of England. On the completion of his studies he spent a year in his father's office; and in 1833, on the recommendation of the late Mr. Edward Pease, he was admitted into the office of the Stockton and Darlington railway at Darlington as an improver, anxious to obtain all the benefit he could from the staff of the oldest railway company in the kingdom. Here he had access both to the accounts and to the engineering plans of the railway, and though never articled, was mainly instructed by the late Mr. T. Storey, M. Inst. C.E., besides having the indirect advantage of contact with the officials of the line. In December, 1835, he was appointed by Mr. Robert Stephenson, M.P., Past-President Inst. C.E., one of the Assistant Engineers to Mr. Thomas L. Gooch, M. Inst. C.E., on the London and Birmingham railway, and was placed in charge of a length of 10 miles, from Birmingham to near Hampton in Arden. On the completion of the line between Birmingham and Rugby, on the 7th of March, 1838, he was appointed Resident Engineer at Birmingham of that section; and finally, on the 12th of June, 1840, the directors resolved "that Mr. Dockray be appointed Resident Engineer for the entire line of railway." This appointment he retained on the amalgamation of the London and Birmingham railway in the London and North-Western system. During the time he occupied this post he carried out the following branch railways—the Coventry and Leamington;

the Coventry and Nuneaton; the Rugby and Leamington, and the Buckinghamshire. The labour and anxiety involved in the execution of these works, in addition to his duties on the main line, brought on a severe nervous and neuralgic affection, which resulted in his losing the sight of one eye. After several years' suffering he, on the 18th of September, 1852, resigned his office of Resident Engineer of the southern division. Previous to this, in October, 1845, the directors presented him with the sum of one thousand pounds, as a testimony to "the engineering skill, zeal, and assiduity" which he had displayed "during the whole period of his services." Mr. Dockray was also presented with a large silver snuff-box, on the opening throughout of the London and Birmingham railway on the 17th of September, 1838, by the clerks and overlookers connected with his department. A larger testimonial, given him on the 27th of December, 1848, by seven hundred brother officers and private friends, consisted of a service of plate of the value of £200, a purse of sixty guineas, £500 stock of the London and North-Western Railway Company, and a portrait of himself by the late Mr. Henry Phillips. Mr. Dockray, on his appointment to the post of Resident Engineer in 1840, went to live at Berkhamstead, removing to Hampstead in the following year. On retiring from professional life, he went to Ramsgate for a few years, but returned to Hampstead in the winter of 1856. Finally, in 1862 he removed to Lancaster, where he remained for the rest of his life. Mr. Dockray, when in health, was a very active, intelligent, and energetic man, fond of his profession, and desirous of carrying out all the work he undertook on the most improved methods. Precise and exact in everything, he was rather a good administrator than possessed of much originality or genius. Nevertheless Mr. Gilbert Scott, R.A., the architect, wrote of the round engine-house and other buildings constructed by him at the Camden station,[1] as models in their way—not knowing who designed them.[2] In person he was under the ordinary size, but well formed, and capable of going through more work than his physique implied. For many years he interested himself in benevolent pursuits, and in such public business as his health allowed him to undertake. He was a constant visitor at the Hampstead workhouse; and at Lancaster was secretary to nearly all the Church Societies, a visitor at the national schools and the dispensary, and a member of various committees of religious and charitable institutions. He was elected a Member of the Institution on the 13th of June, 1843; and, in 1849, received a Telford medal for his "Description and Drawings of the Camden Station, London and North-Western Railway." He died at Lancaster on the 8th of September, 1871, in his sixtieth year.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. viii., p. 164.

[2] *Vide* "Remarks on Secular and Domestic Architecture" (2nd edition), p. 222. 8vo. London, 1858.

MR. PHILIP HARDWICK, R.A., was born on the 15th of June, 1792, in London, and was the son of Mr. Thomas Hardwick (a pupil of Sir W. Chambers), the architect of Marylebone Church and Christ Church, in that parish. He began his professional life with great advantage as his father's pupil and successor, and gave considerable attention to what may be called the business part of the profession. He became a student in the Royal Academy in 1808, and subsequently spent a short time in Italy. In 1815 he was at Paris when the Allied Armies occupied the city, and in the following year obtained the first of a long series of appointments of a profitable kind, on being chosen architect to Bethlehem and Bridewell Hospitals. In the autumn of 1818 he returned to England, and began to practice independently of his father. Soon after, he married the daughter of Mr. John Shaw, an architect of some reputation. Mr. Hardwick was the architect of the St. Katherine's dock-house and warehouses, the successful construction of which on difficult ground, in 1825, spread his reputation far and wide. Soon afterwards he was appointed architect to the Goldsmiths' Company, and erected their new Hall, which was opened in the year 1836. Few modern architects have left a better monument of their skill than this building, in which the distribution of the rooms is at once magnificent and picturesque, while the exterior presents a breadth and simplicity as strikingly characteristic of the man as they are architectural qualities appropriate to the use and position of the building. His next work of public importance was the entrance portico to the Euston Station of the then London and Birmingham railway. It is of the Doric style of architecture, and was finished in the year 1838. He also built the Globe Insurance Office and the City Club, and carried out large additions to St. Bartholomew's Hospital. In the year 1842 he commenced a new hall and library for the Society of Lincoln's Inn; but failing health compelled him to place the works in the hands of his son, Mr. P. C. Hardwick.

Mr. Hardwick was singularly well fitted to fill situations of trust. Besides the surveyorship to the Goldsmiths' Company, he held the post of surveyor to St. Bartholomew's Hospital, the Charterhouse, the Westminster Bridge Estates, Greenwich Hospital, and some other trusts. He was the private architect to the Duke of Wellington, and managed the large London estates of Lord Portman. The Victoria and Euston Hotels at the Euston terminus were planned and carried out by him. He designed many private residences in this country; among them Babraham, near Cambridge, for Mr. H. J. Adeane; and he made alterations in the Bishop's Palace at Hereford. In the year 1844 his health failed so completely, that he was compelled to confine himself to such practice as could be followed in his own room; but he was still enabled, though with much pain, and in constant bodily suffering, to attend committees; and at none was he so regular as at the meetings of the Royal Academy. He was elected A.R.A. in 1839, R.A. in 1841, and in 1850 was appointed to succeed Sir Robert Smirke as treasurer and trustee of that body; but he was compelled, by increasing infirmities, to resign in the year 1861, and to withdraw from all participation in the practice of his profession, as well as from the society of his friends. He was elected a Member of the Institution of Civil Engineers on the 13th of April, 1824, a fellow of the Royal Society in 1828, and served for some time on the council of the latter body; and he took much interest in the labours of the Geological, Antiquarian, and other societies. Mr. Hardwick was one of the founders of the Royal Institute of British Architects, and received the Queen's gold medal in 1854. After upwards of twenty years of bodily suffering from a complaint in the spine, and weakness resulting from an extensive disease of the heart, he went to reside at Wimbledon, where he lived for the last five years of his life, gradually becoming more feeble, and died on the 28th of December, 1870, in the 79th year of his age. Mr. Hardwick was active and energetic,—had a generous nature, and was a man who personally merited the confidence which was placed in him by persons of all stations; and his cultivated intelligence, his high sense of honour, and his straightforward conduct reflected credit upon the profession to which he belonged.

MR. JOHN BERNARD HARTLEY, the only son of Mr. Jesse Hartley, Engineer and Dock Surveyor at Liverpool from 1824 to 1860, was born at Dungarvon, county of Waterford, on the 3rd of September, 1814. His early youth was passed in Yorkshire, at Pontefract and the immediate neighbourhood, where the family of the Hartleys had resided for a considerable period, engaged as county surveyors and bridge-builders, and in the designing and construction of important engineering works. He received his primary education at Giggleswick Grammar School, near Settle in Yorkshire, and lastly under the Rev. William Shepherd, LL.D., the celebrated divine and excellent scholar of Liverpool. In 1829, at the age of fifteen, he was taken into training by his father, and placed in the millwright's shop at the Dockyard Liverpool. It was whilst engaged here, and in the other workshops attached to the Dock Estate, that young Mr. Hartley became initiated into a practical knowledge of the details of his profession. Subsequently, and with a further educational view, he was, in 1835, articled for a short term to the late Mr. James Walker, Past-President Inst. C.E., an intimate friend of his father.

In 1840 Mr. J. B. Hartley commenced business in Liverpool on his own account. Up to this time he had mainly assisted his father in works and engagements, among which may be enumerated the Manchester and Bolton Railway, the Harrington Docks near Liverpool for the Harrington Dock Company, surveys of Sunderland Harbour, of Port Carlisle, and of Whitehaven Harbour, besides surveys, inspections, and reports on works of a minor character. In November, 1842, he was appointed Consulting Engineer for the new works then about to be commenced by the Hull Dock Company; and between that date and October, 1858, when he resigned the appointment, he had designed and executed the Railway Dock with its sheds and warehouses, the Victoria Dock and Basin, the Ferry-boat Dock and Piers, and the Junction Dock Warehouses. The area of water-space was increased by this dock-extension at Hull from 26 acres, or thereabouts, to 49 acres. On the successful completion of these works, the following resolution was unanimously passed at the Annual General Meeting of the Company, held on the 2nd of February, 1854: "That Mr. J. B. Hartley be informed that the Court of Proprietors of the Hull Dock Company entirely agree with the expression contained in the Annual Report of their Directors, of the zeal and ability with which Mr. Hartley has conducted the extensive works intrusted to his management, and brought them to a satisfactory termination; and, as a mark of the high estimation which the Proprietors of this Company entertain of the character and professional talents of that gentleman, of their personal esteem, and as a memento of his long connection with the Port of Hull, the Directors are hereby authorized to expend the sum of £105 in the purchase of such a testimonial as Mr. Hartley may be pleased to select, to be presented by them to

Mr. Hartley on behalf of, and in the name of, the Hull Dock Company."

In 1847 Mr. J. B. Hartley was appointed one of the surveying officers for Admiralty inquiries, under the 9th and 10th Vict., cap. 106, and in that capacity held inquiries on Bills for the Southampton and Dorchester Railway, the Portsmouth and Fareham Railway, the Windsor and Slough Railway, the Windsor, Staines, and South Western Railway, the Swansea Docks, the South Wales Railway, and the Staines, Ascot, and Wokingham Railway. He was also engaged at this time, and subsequently, on the lighthouses at the mouth of the Lune near Lancaster, the Morecambe Bay Docks and Harbour, the Hull and Barnsley Railway, the Pontefract and Goole Railway; also for docks at Purton Pill on the Severn, the drainage of Port Madoc, the docks at Silloth Bay, a graving dock at Grimsby, and on a proposed scheme for docks and a harbour at Cardiff. He was also consulted on works for the improvement of the ports of Bremerhaven and Genoa, as well as at various other places where questions arose relating to the construction of dock and harbour works. In July, 1847, he was specially appointed by the Liverpool Dock Trustees to act, in conjunction with his father, as Engineer of the Liverpool Docks. But by far the most arduous and anxious labours were those which occupied him during the contest that arose on the proposal to construct a deep-water basin and docks at Birkenhead, on designs prepared by the late Mr. James Meadows Rendel, Past-President Inst. C.E. From 1844 to 1856, in every session of Parliament, this contest was maintained almost without intermission. In 1855 the warfare ceased, by the transfer of the Birkenhead Dock Estate to the Corporation of Liverpool, from whose hands it passed, on the 1st of January, 1858, to the Liverpool Dock Trustees, since recognised under the title of "The Mersey Docks and Harbour Board." In the interval that elapsed between the purchase of the Cheshire or Birkenhead Estate by the Corporation of Liverpool and its transfer to the Liverpool Dock Board, as well as subsequently, Mr. J. B. Hartley held the appointment of Engineer of the Birkenhead Docks. He also superintended on behalf of the Corporation of Liverpool, and in conjunction with the late Sir William Cubitt, Past-President Inst. C.E., the construction of the Prince's floating Landing-stage at Liverpool.

Associated as Mr. J. B. Hartley was throughout the whole of his professional career with his father in the construction and management of the Liverpool Docks, any record of the life of the younger Hartley would be necessarily imperfect that did not include a brief allusion to his father Mr. Jesse Hartley, and also some account of the Liverpool Docks, the scene of their united labours.

MR. JESSE HARTLEY was born near Pontefract, Yorkshire, in 1780, and died at Liverpool in 1860; he was a man of ruddy complexion, a powerful bodily frame and robust constitution; and was of the old school of practical Engineers, in a great measure self-taught. His father Hugh Hartley was Bridge-master for the West Riding of Yorkshire, his brother Bernard succeeding the father, while his nephew Bernard Hartley, son of the above, is at this time Bridge-master of the West Riding. Jesse Hartley worked under his father in early youth as a mason; but from the age of thirteen he was partly engaged in office duties and partly on the works at Ferry Bridge, then in course of construction. Before he was fifteen he had visited Lancaster, and made sketches and memoranda of the then new bridge, by Mr. Thomas Harrison, of Chester, and the new canal aqueduct, by Mr. John Rennie, over the River Lune. In 1811–12 he went to Ireland for the Duke of Devonshire, to complete the bridge at Dungarvon. Subsequently he became Bridge-master to the Salford Hundred; and in the year 1824 he was selected by the Liverpool Dock Trustees to be their Surveyor at an annual salary of £1000. In the competition that preceded this appointment Mr. Jesse Hartley became acquainted with the late Mr. Albinus Martin, M. Inst. C.E., also a candidate, and the friendship thus formed extended to the son, and became firm and lasting through life. Mr. Jesse Hartley completed the Grosvenor Bridge, over the River Dee, near Chester, his consent to undertake the work being given, on the condition that no alteration should be made in the external design of the architect, Mr. Harrison, who from advanced age and declining health was precluded from taking an active part in the construction, but that the interior and all practical points should be left to him. Under the superintendence of Mr. Jesse Hartley this bridge, with its fine stone arch of 200 feet span, the largest single-span stone arch in existence at the time, was completed in 1832.[1] As a Dock Engineer, Mr. Jesse Hartley is admitted to have occupied a very high position. Possessing great natural sagacity, and imbued with an innate perception of the leading features of constructive design, he speedily acquired a profound, as well as an extensive knowledge of the requirements of that branch of science to which he devoted himself; and in the design and construction of the numerous docks of Liverpool, he has left monuments of his skill as an Engineer, which will endure as long as the fame and commercial prosperity of the port.

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[1] *Vide* Transactions Inst. C. E., vol. i., p. 207, for description and details of this bridge.

The style of work introduced by Mr. Jesse Hartley was peculiarly his own. In the earlier periods he used ashlar,[2] dressed and worked to the greatest mechanical perfection; in his latter years rubble-work was adopted both for dock and river walls, with granite-rubble carefully jointed for face-work. Then the forms of construction adopted in the sills, platforms, and sluicing culverts of his dock-entrances, the dock-gates, bridges, fire-proof warehouses, shed-roofs, dock-buildings, and also much of his other work, had each a distinctive character, specially fitting it for the object intended to be served. The lighthouses and telegraph stations along the coast, from Liverpool to Holyhead, were under the control of the Dock Surveyors; and most of the buildings connected with the system were constructed by the Hartleys.

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[2] The ashlar masonry was worked after an original and peculiar manner. The stones, new red sandstone, from Runcorn and Weston Point, ranged in dimensions from 20 cubic feet up to 120 cubic feet. The mason commenced work by dressing (hewing) the first bed, margin drafts square to the face, true out of winding, cross-drafts 12 inches apart, the tool bats also square to the marginal drafts. The whole bed was then close picked down and square boasted off. An inspector, with straight edge, tried the bed before it could be passed. Face, joints, and second bed were worked in a similar manner after having been tried, squared, and passed if approved of. If a stone in setting did not joint stone-and-stone to the extreme back of the joint, though 6 feet wide or more, it was made to do so at the expense of the face, which was projected and worked off from a stage in front. The backing was red sandstone rubble, set flush in mortar and grout, about 1 cube yard of mortar to 3 cube yards of rubble. The strength of the work was in the rubble, not in the carefully-hewn ashlar, and this Mr. Hartley acknowledged in his later years, by substituting rubble for ashlar. The system of measurements and bookkeeping was also special. Materials of all sorts were entered and followed up through every change to their final completion and place in the works. Stone, for instance, came in cargoes by water with an invoice, but each cargo was specially marked, and each stone remeasured and marked with letter or number to distinguish the cargo from every other cargo. This letter or number, or both, was preserved on the worked stone, and when set and measured in the dock, wall, or other part, was entered by the measurer with the dimensions. All the work was plotted in courses as set, both on plan and in elevation, the work of each week for a month having a special colour (the weeks being numbered from 1 to 4). The course, with counterforts, being plotted and measured, the cube of the ashlar deducted from the cube of the entire course, gave the cube of the rubble. Every stone could thus be followed to its final place in the work. It would require a long treatise to describe the entire routine of check and measurement, counter check and remeasurement, showing any loss by waste, with explanatory reasons. Some of the masonry, as granite and limestone, was paid for by bed joint and face (superficial) measure, and by the cube for setting. Working and setting were usually done by contract, machinery, staging, stone, and mortar being found. The red sandstone ashlar, worked as described, cost, complete, stone included, about 30*s.* per cubic yard in the dock walls.

The area of the Liverpool Dock Estate, at the time when Jesse Hartley first entered on the duties of Dock Surveyor, was 123 acres, including a water-space of 70 acres in wet docks and basins. At the time of his decease the area of the water-space was 251 acres, and the entire area of the estate had been increased to 866 acres. The river frontage, which at the earlier period of 1824 was about 3,000 yards in length, had been increased by extension in opposite directions, north and south, to 10,000 yards. The tonnage of the port, which, in 1824, was 1,180,914 tons, amounted in 1861 to 4,977,272 tons, while the revenue from duties on tonnage and goods had increased in the same interval from £130,911 to £444,417. During this period of thirty-seven years, the whole of the Liverpool Docks, with the exception of the Prince's Dock, had been built, rebuilt, deepened, or altered; and it is to the Hartleys, father and son, that the entire honour is due of designing, superintending, and carrying out this vast amount of engineering work. With the exception of the excavations, nearly the whole of the dock-extensions were executed by workmen under the immediate direction of the Messrs. Hartley. As the estate increased in extent, the superintendence of the repairs and maintenance alone added materially to the responsibility. For the last twenty years of Mr. Jesse Hartley's life, the expenditure in new works on the Liverpool Dock Estate averaged £205,000 per annum, the highest amount being over £350,000, while the repairs and maintenance alone averaged £42,200 per annum, increased during the final ten years, owing to the great extension of the docks, to an average of nearly £62,000 per annum. The number of men of all grades employed at weekly wages averaged 1650, ranging sometimes, in the busiest seasons, as high as 2,200. Thus, to the responsibility of the Engineer, in the preparation of the designs for the intended works, were superadded the onerous duties of the contractor for their execution. Mr. Jesse Hartley, however, would not give evidence before Parliamentary Committees; and neither father nor son published any work on the Liverpool Docks as designed and carried out by them, but only on the Chester Bridge.

It was in opposition to the wishes of his father, who thought that the management of the Liverpool Docks was sufficient to occupy their joint attention, that Mr. J. B. Hartley undertook, in 1855, for the Corporation of Liverpool, as already intimated, the task of redesigning, with a view to ultimately carrying out, the Dock Works at Birkenhead.

The annual contests the Birkenhead schemes had occasioned were nearly at an end; but it was not until the session of 1858 that the final plans, as designed by Mr. J. B. Hartley, were sanctioned by Parliament, and the works, as they were destined to be carried out, fairly commenced.

Mr. Jesse Hartley had always stedfastly refused to be in any way connected with the Birkenhead project; and thus the whole of the new dock-work on the Cheshire side of the Mersey came under the sole superintendence of his son. How much labour and attention this involved will be understood when it is mentioned that the area of the Birkenhead (or Cheshire) Estate was 497 acres, and that the water-space intended to be formed into docks, and of which only about 7 acres had been hitherto constructed, amounted to 167 acres. The works, from their commencement, were prosecuted under Mr. J. B. Hartley vigorously, the system pursued being similar to that adopted at the Liverpool Docks. In a short time upwards of two thousand men were employed. The annual expenditure averaged £270,000; and for the year 1861, when Mr. J. B. Hartley retired, it amounted to nearly £350,000. But by this time Mr. J. B. Hartley's health had failed him, and, acting under advice, he, in August, 1860, left England with the intention of spending the winter months in the warmer climate of the Mediterranean. His father's death, in the same month, summoned him hastily home again, to leave as soon as the arrangements consequent on that loss had been completed. Previous to his departure, however, the Dock Board appointed him successor to his father as Engineer of the Liverpool Dock Estate, at the full salary of £3,500 per annum. In May, 1861, he returned to England, considerably better, but by no means permanently restored to health. His old complaint, neuralgia, soon made its reappearance, and compelled him, in December of the same year, finally to resign his appointment as Engineer of the Liverpool Dock Estate, and retire from all the active duties of his profession. The Dock Board, not willing to sever the tie that had bound him so long and faithfully to their interests, appointed him their Consulting Engineer, at a retaining salary of £500 per annum.

In personal appearance Mr. J. B. Hartley was of medium height, light hair and complexion, and, with the advantage of a superior education, possessed many of the best characteristics of his father.

Immediately on quitting the Dock service Mr. J. B. Hartley left Liverpool, and went to live at Letrualt, in Dumbarton on the

Clyde, where, free from the ever-recurring toil and anxiety of his profession, he for several years lived in the enjoyment of the pure atmosphere of this sheltered home in the Western Highlands. His health, however, did not permit him to remain here constantly, as he would have wished; he was repeatedly compelled to seek relief at the Spas, in Switzerland, and other similar places of resort. In the autumn of 1869, shortly after one of his periodical visits to the Continent, he fell into his last illness, and, after much suffering, died on the 14th of December, 1869, and was buried in the churchyard at Stirling, on the 21st of the same month, the day of his funeral happening, by coincidence, on the anniversary of his father's birth.

Mr. J. B. Hartley was elected a Member of the Institution of Civil Engineers on the 11th of February, 1840. On the 23rd of June, 1840, a Paper of his was read, "On the Effects of the Worm on Kyanized Timber exposed to the Action of Sea Water, and on the Use of Greenheart Timber from Demerara, in the same situations." In this Paper it was shown that oak timber, whether kyanized or not, suffered equally from the ravages of the worm, whereas greenheart, in similar situations, that is, for clough-paddles, for sill-pieces, and planking of dock-gates, remained untouched and perfectly sound. On the 18th of May, 1841, he also contributed a Paper, "On the Formation of Embankments and the filling-in behind retaining walls," wherein he described and recommended the method adopted by his father on the Manchester and Bolton Railway. The foregoing, with some observations on the system of pile-driving pursued at the Liverpool Docks, addressed to the Meeting on the 16th of April, 1844, comprise all that has been published of his communications to the Institution; and his absence from London, except during the busy Parliamentary season, and the close and constant attention he felt constrained to give to his engagements at Liverpool, gradually drew him away from attendance at the Meetings of the Institution.

Mr. ALBINUS MARTIN was born at Beckington, in Somersetshire, on the 21st March, 1791. His father was a surgeon, who, adopting the principles of the then existing French Revolution, advocated them so warmly as to render himself obnoxious to his influential neighbours; and becoming an object of suspicion and persecution, was obliged to fly to America, where he was kindly received by Washington, and was honoured with his friendship. Albinus, who was an only son, remained in England, under the care of relatives; and was educated with the view of embracing his father's profession, and of following him to the land of his adoption. But the career of the elder Mr. Martin in America came to an untimely close; the yellow fever was raging around him, and being persuaded that the evil arose, in a great degree, from improper drainage, he sought to convince the inmates of a tainted house that they were poisoned by the exhalations of a drain which ran through it. In order to test his views the drain was opened; he inhaled the noxious gases as they rose, and he proved in his own person the correctness of his theory, for he was struck with fever, went home, and died. The death of the father changed the destination of the son. The profession of medicine was abandoned; that of architecture was ultimately adopted, and Mr. Martin became the articled pupil of Mr. Joseph Woods, a member of the Society of Friends, and a gentleman alike distinguished as an architect and as a man of letters. With this gentleman he served his time, and he was also a student in architecture at the Royal Academy. Whilst still articled to Mr. Woods, Mr. Albinus Martin was, for a time, transferred to the office of Mr. James Savage, an early member of the Institution of Civil Engineers—in the days when Telford was President—and who combined the profession of a Civil Engineer with that of an Architect. In Mr. Savage's office Mr. Martin prepared the drawings, and witnessed the execution, of many important works; and in 1809, on the failure of Trevethick's tunnel under the Thames, Mr. Savage, as well as other engineers, prepared designs for carrying out the abandoned work. Mr. Martin assisted him, and thus became identified, in a subordinate capacity, with the efforts to solve that great engineering problem, which, however, it was reserved for the elder Brunel to accomplish, twenty years later. On the completion of his pupilage Mr. Martin commenced practice as an architect, and jointly with the late Mr. S. Beasley, erected the first English opera house, in Wellington Street, Strand, and a few other less important buildings; but he soon abandoned architecture for engineering; and became successively the Surveyor of the Cromford canal, the Resident Engineer of the Leeds and Liverpool canal, the Manager of the collieries of the Earl of Balcarres, and the Bridge-master of one division of the county of Lancaster.

In the year 1824, when the then existing means of communication between Liverpool and Manchester were felt to be quite inadequate, and when the merchants and manufacturers of those towns revived the project of a railway to connect them, Mr. Martin was the Engineer of the Leeds and Liverpool canal, which, by means of a branch from Wigan to Manchester, had a share of the carrying-trade between this latter town and the great seaport at the mouth of the Mersey. Consequently, when, in the spring of 1825, the Bill for the Liverpool and Manchester railway was brought before a committee of the House of Commons, Mr. Martin was necessarily engaged in defending the interests of the canal company in whose service he was. The bill, however, was withdrawn, only to be again brought before Parliament in the following year; but by that time Mr. Martin had closed his connexion with the canal, and was free to act in accordance with his own judgment and sympathies. He had maturely studied the question, and clearly comprehending and appreciating all the advantages of a railway system, warmly co-operated with his friends, Mr. Sanders, of Liverpool, and the two Stephensons, in everything that could promote the success of the new undertaking.

Ten years later he was placed on the staff of the London and Southampton—since known as the London and South-Western—Railway. At about the same time, the late Mr. Locke, M.P., Past-President Inst. C. E., became the Chief Engineer of the line, and under his superintendence Mr. Martin finished the works which had been begun by Mr. F. Giles, and constructed those which remained to complete the line. With this Company Mr. Martin remained for thirteen years, as Manager and Resident Engineer; and when, in 1849, he resigned the position, he received from the Directors a spontaneous vote of thanks for his able and faithful services; and—what to him was probably a more gratifying compliment—a token from the working men and others connected with him in the service of the line, of the friendly feelings which had ever subsisted between them. This token took the form of a handsome presentation of plate, bearing an inscription to the effect that it was "From twelve hundred and thirty-five fellow-labourers, in grateful remembrance of the kindness and goodness which had ever marked his conduct to those associated with him." On leaving the London and South-Western railway, Mr. Martin entered into general practice, and was principally engaged as a consulting engineer, and as a referee on engineering and colliery questions, an employment for which not only his great experience, but his fine tact and his inflexible uprightness peculiarly fitted him. This occupation he followed until the attacks of his hereditary malady, the gout—to which he had always been subject—became more and more frequent, and interfered with his professional engagements. He then thought it right to retire from practice; but until his last illness the younger members of the profession, who had the privilege of his friendship, were allowed to draw freely upon his sound judgment and rich store of professional knowledge.

Failing health and frequent absences from London led him, in 1864, to tender his resignation as a Member of the Institution of Civil Engineers; but the Council, at its meeting in December of that year, passed the following resolution:—

"That the resignation of Mr. Martin be not accepted; but that, as a mark of respect for his long and honourable career in the profession, he be requested to allow his name to remain on the books as a Life Member."

Mr. Martin deeply felt the honour thus conferred; and up to a very recent period his numerous professional friends had the pleasure of meeting him from time to time at the Institution, in which, since his election in 1849, he had always taken a lively interest.

In the full enjoyment of life, and, with mental faculties unimpaired, he fell sick on the 11th September, and expired on the 17th October, 1871, in his eighty-first year. Few men have been so universally esteemed and beloved; for although by age and experience he was one of the fathers of the modern school of engineers, and although many of his works attest great professional skill, yet his claim to distinction rests in no inconsiderable degree upon his social and private character. Endowed with a remarkably retentive memory, and possessed of a fund of information on almost every subject, he poured his knowledge forth, unconsciously as it seemed, and without the least desire for display. His heart was full of benevolence and the love of others, and there was no room in it for vanity and the love of self. He was beloved by all who could appreciate sterling honesty and fearless truth; yet his sparkling and kindly wit never hurt the feelings of others, and never degenerated into sarcasm; his sympathy with all mankind was such, that he had an intuitive perception of what was passing in the minds of his fellow-creatures; and even their foibles he regarded with tenderness. The irresistible charm of his conversation and manner attracted old and young alike; and once a youthful friend asked for the secret of his popularity: Mr. Martin's reply was characteristic: "I don't know," he said, "that I am more popular than my neighbours; but if I am, it must be because I am always careful not to tread upon other people's toes." Few men, in any circle, have passed away deservedly leaving so many friends and so few enemies.

Mr. JAMES NEWLANDS was born on the 28th of July, 1813, at Edinburgh, where his father carried on business as a rope-manufacturer. He was educated at the High School, under the late Mr. Benjamin Mackay, and subsequently applied himself to the study of mathematics and natural philosophy, under Professor Wallace and the celebrated Professor Leslie, in the university of that city. At the same time he acquired great facility as an artistic and mechanical draughtsman, and much skill as a theoretical and practical musician. About the year 1827, Mr. Newlands entered the office of the late Mr. Thomas Brown, then architect of the Edinburgh corporation; and, after various changes, he was engaged from 1833 to 1836 as assistant to Professor D. Low, who, at that time, filled the chair of Agriculture in the university. While thus engaged he drew on wood the illustrations for a large work on agriculture and agricultural implements; he designed farm buildings, and illustrated, by descriptions, the principles upon which they should be designed; drew out the designs for the classes, and superintended the making of models of farm buildings and agricultural implements now in the University Museum.

During this period, also, Mr. Newlands practised writing on subjects connected with his work, studied mechanics and mathematics, and in 1838, acquired some knowledge of chemistry. He also gradually obtained practice as an architect, and by indomitable perseverance, energy, and sheer hard work, he laid the foundation of the varied knowledge he possessed, and which ultimately was of such service to him. As a proof of his energy, it may be mentioned that he, one afternoon about 3 o'clock, undertook to have an article on a certain subject in the printer's hands by 6 o'clock on the following morning, with wood-cuts drawn ready for cutting, which he accomplished in time by never leaving his chair till the work was completed.

Mr. Newlands' position as an accomplished writer was recognised so early as 1838, as he was engaged to write for the seventh edition of the "Encyclopedia Britannica." He wrote, chiefly in the evenings, the articles "Ropemaking," "The History of Steam Navigation," and others of minor importance. From 1844 to 1847 he was engaged, to some extent, on railway works, in addition to his ordinary business, connected with designing and superintending the erection of farm and other buildings, valuing land, and damage claims resulting from railways passing through estates, &c.

Whilst thus working himself upwards to a distinguished and honoured position, the attention of Mr. Newlands was drawn, towards the close of 1846, to an advertisement for an efficient person to act as borough engineer for Liverpool, and he determined to enter the field as a candidate, seeing in the opening a wider sphere for the exercise of his enlarged and enlarging capacities. The town had been visited by an epidemic of a very fatal character, traceable, it was thought, in some degree to defective sanitary arrangements; and Mr. Newlands having given proof of his intimate and extensive acquaintance with sanitary science, he was selected from five candidates, and on the 26th of January, 1847, was appointed the first borough engineer of Liverpool. Immediately upon entering into office, he set about a searching investigation of the causes which regulate or determine the hygiene of large and populous towns, with a view of applying the principles to the benefit of Liverpool. His examination showed that the means of effecting physical cleanliness in the town were very defective. The sewerage had been carried out in a desultory and unsystematic manner, and only to a very imperfect extent. The methods of removing the solid refuse, which inevitably accumulates among a large population, were also defective; and he at once betook himself to laying out a complete system of sewerage, whereby the liquid impurities of the town might be rapidly and effectively carried away, and so disposed of as not to be detrimental to the surrounding neighbourhood. To secure this object he made a careful and exact survey of the town and its surroundings, involving somewhere about three thousand geodetical observations, and resulting in the construction of a contour map of the town and its neighbourhood, on a scale of one inch to 20 feet. From this elaborate survey Mr. Newlands proceeded to lay down a comprehensive system of outlet and contributory sewers, and main and subsidiary drains, to an aggregate extent of nearly 300 miles. The details of this projected system he presented to the Corporation in April, 1848, in a lucid and comprehensive report, which was adopted by that body in July of the same year. Armed with this approval, he at once set himself to carry the system into practical operation; and, by laborious industry he succeeded in completing a system of sewerage in every respect adequate to the great and still growing requirements of this large and rapidly expansive community. The carrying out of this vast, and in many respects difficult undertaking, involved much mental labour, as well as a great expenditure of physical exertion; the combined effects of which, without doubt, contributed largely to the exhaustion of a bold and vigorous intellect, and the physical prostration prematurely of a robust constitution. In addition to the development of thorough and systematic drainage, the report referred to, which may with safety be said to exhaust the subject of sewerage in all its principles and details, also enters with minuteness into nearly every department of physical hygiene, including water-supply for public and private purposes, laying out of streets and thoroughfares, construction of domiciles, lighting and cleansing streets, and regulating traffic. In point of fact, it elucidates with clearness and precision almost every matter connected with the sanitary arrangements of a great population, and includes well-digested estimates of the cost of construction and maintenance of the system which it recommends for adoption. Indeed, so comprehensive and minute is the information concentrated in this manual, that up to the present hour it remains the text-book for all the sanitary improvements connected with the borough. Besides attending to the great branches of sanitary regulation, Mr. Newlands was indefatigable in carrying out improvements in the paving and management of the streets, which, under his direction, were changed in numerous instances from tortuous and narrow alleys into convenient and handsome thoroughfares, suited by their admirable construction to the traffic by which they are continuously occupied. He designed and carried out the Cornwallis Street and the Margaret Street Baths, besides modifying and improving the previously existing public baths belonging to the town. Under his superintendence the lighting of the streets and thoroughfares of the borough has been established on a system so effective as to compare favourably with that of any town in England, and to have served as a model to many other places. Mr. Newlands was a steady and consistent advocate for the maintenance of open spaces for the recreation of the people; a favourite project of his in this direction having been the construction of a boulevard round the town, coincident with the parliamentary boundary, with streets radiating towards it from the central and crowded districts. In his endeavours to carry out this object he expended much thought and no small amount of labour. The scheme, however, did not meet with the approval of the Council; but had it been executed, a great belt of open road would have encircled the town, equidistant from every part. Already, by the expansion of Liverpool, it would have been actually within the town proper, forming a great playground for the people, and serving, in fact, as a park running through the town.

Mr. Newlands was elected an Associate of the Institution on the 6th of June, 1848, and was transferred to the class of Members on the 20th of January, 1857. When in London he frequently attended the meetings, and occasionally took part in the discussions.

During 1853 Mr. Newlands, in the evenings, after his official labours, revised his articles for the eighth edition of the "Encyclopædia Britannica," and wrote that on "Birkenhead." He afterwards also wrote works on "Carpentry" and "Perspective," illustrating the latter by applying its rules to so intricate an example as bevel gearing. These two works were published by Messrs. Blackie, of Glasgow.

A most gratifying testimonial to the professional ability and practical skill of Mr. Newlands was given during the Crimean war. During the siege of Sebastopol, the camp at Balaclava became a huge seat of pestilence, which spread disease amongst the troops, and greatly increased the difficulties felt by the Allies in their proceedings. The British Government wrote to the mayor and corporation of Liverpool, asking that Mr. Newlands might be permitted for a time to vacate his official post, and proceed to the Crimea as a sanitary commissioner, with the view, as far as possible, of removing the evils under which the British army was suffering. The request was cheerfully complied with. He went forth to new duties, and so effectually did he remedy the evils complained of, that in a complimentary letter which he afterwards received from Miss Nightingale, acknowledging his services, she remarked, "Truly I may say that to us sanitary salvation came from Liverpool."

Mr. Newlands continued to fill the office of Borough Engineer till May, 1871, when, his health being greatly impaired, he retired from the active duties of the office, his services being retained by the Liverpool Corporation as consulting engineer.

Mr. Newlands had a strong, firmly-knit frame, rather under middle-height, and had an unusually large head. He was always known as a hard worker, and had untiring energy and perseverance. His reading was extensive, considering the time at his disposal; and having great observant powers and a good memory, he was an interesting companion. He had a versatile genius, being architect, engineer, author, musician, and artist. Of the two former it is unnecessary to speak farther than to remark, that his sanitary works especially have always been highly approved. His writing was terse and vigorous, the ideas being conveyed in language so well arranged and appropriate, that it seems as if any alteration would impair the whole structure. His penmanship was good, being small and distinct. He was an accomplished musician, playing the flute skilfully; and he accompanied singing on the piano readily, reading even difficult music at sight. His sketches, of which he made some hundreds, attest his powers as an artist; but his large pictures, of which he painted three or four, were better, although painted in early life. They were exhibited in the Royal Scottish Academy's Exhibition, and sold readily.

Mr. Newlands' manner was affable, and he was most punctual in all his engagements. He had genial social feelings, and was much liked by his assistants; while his high-toned morality and deep religious feeling made his example a safe one to follow. He married in the year 1845, but lost his wife in 1848, and never had any family.

Although Mr. Newlands got through so much work, he had not for many years enjoyed good health, suffering as he did from chronic bronchitis, with acute attacks frequently in winter or spring. The first time Mr. Newlands was attacked was in 1843, when his life was despaired of; and in 1846, as the result of overwork during the railway mania, he was ordered by his physician to go to the Continent. Almost every year afterwards he was laid aside for a time, and had often to go abroad for his health. After his retirement from the active duties of the office of borough engineer, his health gradually became worse, and he died at his residence in Liverpool on the morning of Saturday the 15th of July, 1871, being then scarcely fifty-eight years of age.

MR. JOSIAH PARKES was born at Warwick on the 27th of February, 1793. His ancestors were yeomen living on their own land at Netherton, in Worcestershire, from the time of Queen Elizabeth. The family removing, gradually sold the land, which has since proved of great value in mines of coal and ironstone. The grandfather of Josiah Parkes was a wealthy draper and banker in Warwick (not an unusual combination of trades in those days), issuing the banknotes of Parkes and Sons. The two sons of the banker, William and John, carried on a mill at Warwick for carding and spinning wool. Josiah, the third son of John, was educated at the school of Dr. Burney, at Greenwich. At seventeen years of age he went into his father's mill, and there devoted himself chiefly to the machinery department. During this period of his life he had the advantage of the literary and scientific society of which his father's house was the centre: amongst the guests and visitors being Mr. Sergeant Rough, Mr. Basil Montagu, the accomplished family of the Greatheads of Guyscliff where the genius of Mrs. Siddons was first discovered, and Dr. Parr of Hatton, who brought many of his literary and political friends to the hospitable house of Mr. Parkes. In 1820 the manufactory at Warwick was unsuccessful, and discontinued. Mr. Josiah Parkes removed to Manchester, where he was on intimate terms with Dr. Henry, and the great quaker chemist, John Dalton, and occupied himself with inventions for the prevention of smoke, which he abandoned, to carry out, near Woolwich, a new process for refining salt. In 1825 he removed to Puteaux on the Seine, and there formed an establishment where he was often visited by Louis Philippe, then Duke of Orleans. When the Revolution of 1830 broke out, Mr. Parkes, who had been educated in the religious and political opinions of Dr. Priestly, fought on the popular side at the Barricades, and had a workman killed at his side. The Revolution triumphed, but his business was ruined, and he returned to England, fortunately for the cause of agriculture all over the world.

His next work was carrying out for one of the Heathcotes, of Tiverton, a plan for draining and reclaiming a part of Chat Moss, in which he employed steam power for cultivation. The steam cultivation was a failure; but it was here that the great principle of deep systematic drainage dawned upon him, which has been described in an article contributed to the "Quarterly Review" in 1858, by Mr. S. Sidney, at present the Secretary and Manager of the Agricultural Hall Company, from which the following statement has been condensed:—

His observations of the effect of the deep cuttings on the bog led him to make experiments, and by these experiments he discovered the principles of agricultural drainage, which were previously not only unknown but misconceived. The vulgar idea was, and is even with educated men who have never thought about the subject, that agricultural land suffers from rain falling on the surface. Mr. Parkes found that a deep drain began to run after wet weather, not from the water above, but from the water rising from subterranean accumulations below, and that by drawing the stagnant moisture from 3 or 4 feet of earth next the surface it was rendered more friable and porous, easier to work and more easily penetrated by the rain, which carried down air. which is full of ammonia and manure, made it much warmer, and therefore more genial to the roots of the various crops. Without drains a retentive soil is saturated with stagnant water, which remains until evaporated by a warm season, and then leaves the soil hard-baked. Mr. Parkes came to the conclusion that 4 feet, which left a sufficient layer of dry warm surface earth, after allowing for the rise of the moisture by capillary attraction above the water level of the drain, should be the minimum depth. This is now the universally accepted opinion of the best agriculturists in England, France, and Germany. Smith, of Deanston, a very clever man, had previously devised a system of shallow drains, made of broken stones in the gridiron shape. But he missed the principle; he devoted his ingenious mind to devising expedients for getting the surface water into his drains. After a few years of contest the Deanston plan was entirely superseded by the Parkesian plan. In 1843, Mr. Parkes gave evidence before a committee of the House of Lords on agricultural distress and its remedies. He was warmly supported by the Earl of Lonsdale, whose experience as a commissioner of highways had proved the soundness of the system; but nothing could be done without drain-cutting tools and pipes. A Birmingham manufacturer, on Mr. Parkes' suggestion, produced, in 1844, the first set of drain-cutting implements, which have since been brought to such extraordinary perfection. A cheap conduit was still a difficulty. Stones choked up in many soils, and where they had to be broken up and carted to the ground, their cost became enormous. At the Derby show of the Royal Agricultural Society in 1843, Mr. Parkes showed Lord Althorpe a cylindrical clay pipe, saying, "With this pipe, my lord, I will drain all England." This pipe had been made by wrapping a lump of clay round a mandrel, by John Reade—a self-taught mechanic—inventor of the stomach-pump, who was a gardener by trade, and used these hand-made pipes for draining his hot-beds. The council of the Royal Agricultural Society awarded John Reade a silver medal for his pipe, and offered a prize in the following year for a pipe-making machine. This prize was won by John Scraggs, at the Shrewsbury show in 1845. Drain-pipes can now be manufactured quite as fast as kilns can bake them. In 1846, Sir Robert Peel, as an aid to the distressed and frightened agriculturists, passed an Act by which four millions sterling were advanced in loans charged on lands to be drained under Government inspection, on the Parkesian principle. The first loan was nearly entirely taken up by Scotch landowners. A second loan of four millions was granted in 1856; but these eight millions only formed a small proportion of the amount invested in the systematic deep drainage by the private enterprise of landowners and of companies formed for the purpose. By drainage, hundreds of thousands of acres of stiff clay soils, previously condemned to poor pasturage or uncertain crops of corn and beans, have been rendered friable, fit to grow roots, carry sheep, and fall into regular rotation. In Yorkshire, Mr. Parkes, for Lord Lonsdale, at an expense of from £10 to £20 an acre, reclaimed moor land not worth a rent of 1*s.* an acre, and raised its value to £2 an acre. Increased fertility of soil was not the only result. Systematic drainage led to general agricultural improvements; hedgerows and useless timber were cleared away, undulating ridges were levelled, roads made, and buildings erected to accommodate the production of meat as well as corn. It is also in evidence that the idea of pipe instead of brick sewers was first taken from the operations of Mr. Parkes in a Gloucestershire village to which he adapted his system. One of the curious incidents during the introduction of the Parkesian, or scientific system of deep drainage, was the virulent opposition of that able chemist, Baron Liebig, so malignantly prejudiced against everything English. The baron, about the time of the introduction of Mr. Parkes' principles and plans, introduced his patent universal manure, which proved so complete a failure, and seriously damaged the fortunes of the Liverpool chemists who undertook its manufacture. In order to push the sale of the patent manure, Dr. Liebig wrote a letter in its praise, and at the same time solemnly warned English farmers, that deep drainage would reduce their lands to permanent sterility, by driving into the drains the principal elements of fertility. This theory has since been retracted. Mr. Parkes, like other men of original genius, had his foibles. He had not the art of managing men, and consequently a good deal of his early work on sound principles was very badly executed, and brought his system into disrepute. He was intolerant of advice and jealous of opposition, and consequently never adopted the improvements introduced by Mr. Bailey Denton and others, who took advantage of the natural porosity of any tract of soil to diminish the cost of the series of uniform gridiron drains, to which Mr. Parkes adhered to the last. He would never admit that any improvement on his original plan was possible. Still, it must be admitted, it was a great triumph to introduce an entirely new system, to be executed with entirely new tools and machines against the stubborn prejudices of the farmers, within the short space of thirteen years. Mr. Parkes, for his services, was elected an honorary member of the Royal Agricultural Society. Mr. William Bundy, who was Mr. Parkes' assistant for over twenty years, says in a letter to the secretary of The Institution of Civil Engineers, that Mr. Parkes told him on several occasions, that he had got his first ideas of deep draining when a schoolboy at home. A a servant of his father's was digging deep drains to dry a very wet part of a paddock. He asked the old man why he dug so deep—to which he replied, "You see, Mr. Josiah, unless you drain off deep down this stagnant water, there is no room for the rain water to get in." This is the whole of Mr. Parkes' principle in a few words. Since 1860, the general introduction of steam cultivation, which is very deep, has made Mr. Parkes' system of deep drains a necessity, and what farmers, with their natural love of compromise, call moderate depths impossible.

Mr. Josiah Parkes was elected an Associate of the Institution of Civil Engineers on the 11th of March, 1823, when residing at Manchester, on the recommendation of Messrs. Joshua Field, Henry R. Palmer, and James Jones, three of the six founders of the Institution, and of Mr. Bryan Donkin. Three years afterwards he presented an "Account of the Eruption of Water and Bog-earth at Crow Hill on the 2nd of September, 1824," and two sessions later an "Account of the Manufacture of Salt in Bengal," both of which exist in MS. in the archives, the publication of the Papers read and of the discussions upon them, not having been commenced at that early date. He was transferred to the class of Members on the 26th of December, 1837, and in the four following years he contributed five communications, all of which appear in abstract in the "Minutes of Proceedings," and in extenso in the "Transactions." The first of these was, "On the Evaporation of Water from Steam Boilers,"[1] for which a Telford Medal, in silver, was awarded. This was followed by two others "On Steam Boilers and Steam Engines,"[2] and "On Steam Engines principally with reference to their consumption of fuel,"[3] for which a Telford Medal, in gold, was awarded; the Council, in their Report, for 1841, stating that the benefits conferred on practical science by these communications, "exhibiting so much originality, labour, and research," had induced them to confer "on Mr. Parkes the highest honour which the Institution has in its power to bestow." The succeeding Papers were "On the Action of Steam in Cornish Single Pumping Engines,"[4] and "On the Percussive or Instantaneous action of Steam and other Aëriform Fluids."[5] Mr. Parkes served as a Member of the Council in the sessions, 1840 and 1841, and in addition to the communications and to the subjects already referred to, he, during the years 1838 to 1843 inclusive, joined in the discussions on canals and canal boats, the Hamoaze floating bridge, fuel, lighthouse lenses, the "Great Western" steam-ship, agriculture, Moseley's indicator, and the performances of the Old Ford engine artillery, brick-making, the manufacture of iron, pump-valves, and railway axles, and his opinions on these varied questions are contained in the first and second volumes of the "Minutes of Proceedings." He was likewise a frequent donor to the Library at the period alluded to; but active participation in the affairs of the Institution then ceased.

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[1] Minutes of Proceedings Inst. C.E.. vol. i. (1838), pp. 17-20; Transactions Inst. C.E,, vol. ii., pp. 160-180.

[2] Ibid., vol. i. (1839), pp. 54-58; iii., 1-48.

[3] Ibid., vol. i. (1840), pp. 6-14; ii. 49-160.

[4] Ibid., vol. i. (1840), pp. 75-78; vol. iii., pp. 257-294.

[5] Ibid., vol. i. (1841), pp. 149, 150; 409-439.

His contributions to agricultural literature are, "Fallacies of Land Drainage," (1840), "On the influence of Water on the Temperature Soils," and "On the quantity of Rain-water, and its discharge by Draining up from Tiles and Drainage," "On reducing the permanent Cost of Drainage," "On the Philosophy and Art of Drainage, 1868," all of which appeared in the Journal of the Royal Agricultural Society of England, as well as his Reports as Engineer of the Society on the Implement Shows between 1840 and 1846.

In 1854 Mr. Parkes began to retire from his extensive business as a land-drainer, in which he had employed a thousand men. In 1860 he resigned his appointment as Consulting Engineer of the Enclosure Commissioners, and in 1869 finished his last contract, and altogether retired from business. His last important work was for the War Department. The draining, forming, and fixing soil-sliding, broken down sea slopes, in part of the proposed fortifications at Yaverland and Warden Point, Isle of Wight, was commenced 1862, and completed in 1869. He died at Freshwater in that island on the 16th August, 1871. He left behind him a mass of papers, containing the results of experiments on the temperature of soil and other effects of deep systematic drainage, but it is not known whether any of these are in a fit state for publication, as Mr. Parkes' later years were passed in complete retirement from the scientific and engineering world.

MR. SAMUEL POWER, M.A., was born at Waterford, in Ireland, on the 28th of July, 1814. From childhood upwards he was remarkable for his love of study, but, being of a delicate frame of body, he had little taste for the usual rough sports of boyhood. Partly on this account and partly also on account of his serious disposition, his parents intended him for the Church; and at the age of fifteen he entered Trinity College, Dublin, where he greatly distinguished himself, gaining all the prizes and certificates in Classics, the gold medal for Greek, and a scholarship at the early age of between sixteen and seventeen, and the Divinity premium as well as the Hebrew prize in the Divinity course. His younger brother being at that time engaged in the study of medicine, Mr. Power was induced to join in those studies, pursued them with his accustomed ardour, graduated with high distinction both as a surgeon and a physician, and received flattering offers and promises of professional employment.

It appears, however, that these pursuits were not congenial to the young men; and the younger of the two, attracted by the accounts of the wonders of railway enterprize in America, and by watching the progress of the Dublin and Kingstown railway then in course of construction, first served an apprenticeship with Mr. Brassington, C.E., of Dublin, and next resolved to seek his fortune in the New World. In this he was joined by his elder brother, who, sharing his taste for engineering pursuits, gave up all the bright prospects of distinction at home; and the two brothers accordingly proceeded to America, against the advice and remonstrances of their friends and relations,—the elder of the two being at the time little more than twenty years of age. It does not appear that they had any definite object in view, except love of travel and adventure, and a desire to see the wonders of the American continent, and to seek for engineering employment. They sailed for Quebec, ascended the river St. Lawrence, and following the chain of the Great Lakes, rested for a time in the Indian hunting ground of the Chippewas, near Lake Huron. Having built a hunting lodge, they began to examine the country, especially with reference to a scheme for a canal to connect Lakes Simcoe and Caschichan with Lake Huron, by way of the river Severn. They went to explore the rapids and cascades of that wild and beautiful river without an Indian guide, and nearly lost their lives in the pursuit. Mr. Power had in view at that time the publication of a work, on the resources of the country and on the social condition and prospects of settlers, which might be relied on, and in contravention of various untrustworthy descriptions then published. When navigating Lake Caschichan, in a small sailing boat, the brothers were overtaken by a hurricane or tornado, which nearly brought their earthly career to a close; they were swept along by its irresistible force, and their boat was dashed to pieces on a small rocky island, where they nearly perished from cold and hunger.

They did, however, manage to make their escape in a small canoe on the cessation of the storm, and reached the hunting lodge in a very forlorn condition. The winter set in soon afterwards, and kept them ice-bound there for nearly seven months, Mr. Power employing himself mostly in study and writing, and his brother in hunting and trading with Indians to supply the larder. On one of these excursions he chanced to meet a former schoolfellow, then residing with an elder brother in the backwoods, and from the accidental meeting of these two boys resulted some years later Mr. Power's first elevation to name and position in his future, and at that time unthought-of profession of a Civil Engineer.

In the following spring, their means of remaining longer in the backwoods having been lost in the wreck of the boat, they travelled through the United States to New York by the Erie canal as soon as the navigation was opened. Mr. Power at once applied for a professorship in a preparatory college in that city, then vacant by the resignation of Mr. W. H. Herbert, the well-known author. He first obtained the professorship of Greek and Latin, to which was added, in a few weeks, the professorship of chemistry in the same Institution.

In the meanwhile his brother, having submitted his architectural drawings and credentials to Major (afterwards Major-General) MacNeill, the eminent American engineer, obtained an appointment on the Long Island railroad, under Mr. Kirkwood.

It was at this time that Mr. Power resolved to abandon literary pursuits and to adopt the profession of an engineer. He accordingly resigned his appointment at the college, and after studying with his brother the details of surveying and drawing, had no difficulty in obtaining employment with Mr. Mifflin, on the Reading railroad, in Pennsylvania. He subsequently joined the Long Island line, when Mr. Kirkwood was not slow to find out his abilities, and in the course of a year despatched the two brothers to the Charlestown, Louisville, and Cincinnati railroad, 500 miles in length, on which Mr. Power held an important position. On the exploration and surveys of this line some time was spent, but want of funds prevented the prosecution of the works. No less than sixty engineers were employed under the command of Captain Williams, who was associated with Major MacNeill in this undertaking. Seeing no immediate prospect of advancement, and judging that the project would be abandoned for a time for the reason mentioned, Mr. Power and his brother sailed for New York, and then proceeded to Washington, where, through the influence of Captain Williams, they were appointed joint engineers of 50 miles of railway on the Eastern shore of Maryland, under Colonel Kearney. On their way thither, it occurred to the elder brother, that as one must be subordinate to the other on such a work, and as their previous relative positions might possibly be changed, which would be unpleasant, to propose that they should draw lots, the successful one to take the post of chief engineer and the other to return to Washington in quest of employment. This romantic idea was carried into effect; and the younger being successful, Mr. Power returned to Washington.

His next occupation was a survey for a canal of a difficult character under Colonel Abert, chief of the topographical corps. This being completed, he returned to New York, and was forthwith sent by Major Smith, the commandant of New York harbour and garrison, to open granite quarries at Frenchman's Bay, on the northern coast of Maine, for the construction of a lighthouse at the entrance of New York harbour. Experiments were made with large granite blocks, but Major Smith's designs were not carried out. Mr. Power was recalled, and found employment as assistant to Mr. Kirkwood on the Great Western railway in Massachusetts.

He was here joined by his brother, and giving up his appointment, took a contract with him for a portion of the railway, and completed it with great success.

One of the periodical financial crises had at this time occurred, and nearly all public works were suspended in the United States. So Mr. Power, looking round for employment, heard of the works then projected in Canada, through the young man whom the brothers had met near Lake Huron, and who was employed on a canal in that country. He wrote to Mr. Killaloe, the Engineer and President of the Board of Works for the Province, and in reply had the offer of an appointment on the Welland Canal, the great work round the falls of Niagara, which connects Lake Erie with Lake Ontario. His previous varied course of employment fitted him well for this kind of work, which was of an arduous and difficult nature. Although almost prostrated at length by over exertion, both physical and mental, he had the satisfaction of completing this noble work, the locks of which have been considered among the best on the American continent. On Mr. Killaloe's retirement, Mr. Power resigned his situation as engineer of the Welland Canal and returned to England, with many flattering letters and testimonials.

On arriving in London he was appointed by Mr. Brunel, Resident Engineer to the Great Western Docks at Plymouth, which were conducted by him from their commencement until near final completion, when he was called on to embark for India. Mr. Brunel expressed much regret at parting with him, after having had the benefit of his assistance for nearly ten years, and wrote in the highest terms of his ability and integrity.

About this time, that is early in 1857, Mr. Turnbull, M. Inst. C.E., who was then the Chief Engineer of the East Indian railway in Bengal, being in want of efficient assistance for carrying on the Soane Bridge works, situated about 450 miles from Calcutta, made a requisition for a man of special skill and experience, as the works were of exceptional character and magnitude, and were making slow progress. In due time Mr. Power was sent out by Mr. Rendel, the company's consulting engineer in London, and he arrived in Calcutta in June, 1857. It happened that, in the preceding month, the great Indian mutiny had broken out at Meerut and Delhi; the traffic and general trade of the country were paralysed, and the railway works suspended on the greater part of the line. At the end of July the native regiments at Dinapore mutinied, marched to the river Soane, and destroyed all the preparatory works of the bridge, on their way to their memorable attack upon Arrah. It was not until towards the end of 1857, when the country became more tranquil, that Mr. Power was placed in charge of the Soane Bridge. This great work consists of twenty-eight spans of 150 feet each on piers of brickwork, which piers stand upon brick cylinders or wells of 18 feet diameter, there being three wells to each pier. These wells are sunk more than 32 feet below the low water level, through the sandy bed of the river into a bed of stiff clay; the floods rise upwards of 20 feet, and the current is very rapid. As the bridge is nearly a mile in length, contains about a million and a half cubic feet of brickwork, and the site is unapproachable during the annual inundation and floods, much exertion was necessary, and good organization also, to keep pace with the rest of the works. This was effected by Mr. Power, with his able assistant, Mr. Schmidt, M. Inst. C.E., and matters were going on prosperously, when a second outbreak took place in July, 1858. Koer Singh came down with his rebellious troops, and on their way to Jugdeespoor again almost destroyed the works, and brought all to a complete stop for the second time. This inroad was, however, soon suppressed, and work was resumed about the middle of November of the same year, 1858. The loss in time and money by these successive disasters was very heavy, as most of the preparatory works had to be recommenced.

Failing health, from over exertion and exposure, caused Mr. Power to return to England, and he sailed from Calcutta in August, 1860. After a year's absence he arrived again in India in restored health, but the works have been carried on satisfactorily with an approach to completion under Mr. Schmidt, he was not placed as before in exclusive charge of the Soane Bridge, but acted as general assistant on the whole line.

The Soane Bridge was completed in November, 1862, and public traffic was commenced by trains running over it on the 22nd of December of that year, when the line was opened to Benares, 541 miles from Calcutta.

On the retirement of Mr. Turnbull, in the year 1863, Mr. Power was appointed Chief Engineer. He fulfilled the duties of the situation for six years, to the entire satisfaction of the Railway Company, and not less so to that of the Government of India, with whom he was much in contact. Declining health compelled him then to retire, when a farewell address and a valuable service of plate were presented to him by the railway staff.

On reaching Europe in September, 1869, he settled in Coblenz, on the Rhine, with his wife, a daughter of Major Edward Sutherland, of the Royal Artillery, and their only child, a boy. He died there after a few days' illness, on the 28th March, 1871, at the age of 57 years.

If Mr. Power's bodily constitution had been equal to his mental powers, he would probably have reached even a higher position than that which he attained; but his great modesty, retiring disposition, and conscientiousness, made him relinquish professional matters that came before him, from a feeling of physical inequality, brought him home in 1869, and caused him to give up his distinguished position in India. He was a man of a most amiable disposition, kind and affectionate in private life, of singular equanimity of temper, and much esteemed by all who served under him, and also by all who were intimate with him.

MR. THOMAS WICKSTEED was born on the 26th of January, 1806, at Shrewsbury. He was the fourth son of John Wicksteed, of that city—well known in his day as a man of high literary attainments, combined with singular simplicity of character—the friend of Coleridge, Wordsworth, Charles Lamb, and Hazlitt.

Thomas Wicksteed was educated at Shrewsbury School, under Dr. Butler, afterwards Bishop of Lichfield; and at sixteen years of age he was sent to London, to reside with his father's old friend, Arthur Aikin, Secretary of the Society of Arts, with whom he lived for some years in the Society's house in the Adelphi; and where he made the acquaintance of many of the leading literary and scientific men of the day. By Mr. Aikin's advice he was articled to Mr. Alexander Galloway, the well-known mechanical engineer, of West Street, Smithfield, where he obtained a knowledge of mechanical details, afterwards of much aid to him in his professional avocation as a civil engineer; and at this early period he displayed, in various ways, that energy of character for which he was remarkable through life. On the termination of his pupilage with Mr. Galloway, he became an assistant to Mr. Henry R. Palmer, Vice-President Inst. C.E., the Engineer to the London Docks, and remained with him until September, 1829, during which time extensive additions were made to the docks and warehouses.

The office of Engineer to the East London Waterworks Company becoming vacant in 1829, Mr. Wicksteed was selected for the post out of thirty-two candidates. In the autumn of the same year he married Eliza, the third daughter of the late Mr. John Barton, of London, by whom he had seven children, five of whom survive. He devoted himself with zeal to the interests of the East London Waterworks Company; and with such economy and success did he manage the works that, although costly additions to the reservoirs and pumping-engines had to be made, yet the company became increasingly prosperous from the date of his appointment. This was brought about by the large saving he effected in the consumption of fuel, partly by his strict watchfulness over details, but principally by his introduction of the Cornish engine, in place of the less economical pumping-engines previously in use. It was in the year 1835 that his attention was first directed to this form of engine; and after he had visited the Cornish mines, conducted experiments, and published the results obtained, the directors of the company, in 1837, were induced to transplant an engine from Cornwall to their works at Old Ford. So great was the economical result that it was received with incredulity; and Mr. Wicksteed, therefore, acting upon the advice of the late Mr. James Walker, President Inst. C.E., entered upon, and carried out a set of most careful experiments upon the engine, extending over upwards of a year, to establish the correctness of his views. He communicated these experiments and his conclusions to the Institution of Civil Engineers, in a Paper entitled "An Experimental Inquiry concerning the relative power of, and useful effect produced by, the Cornish and Boulton and Watt pumping-engines, and cylindrical and waggon-head boilers;" but as some of the details were not completed in time to allow of its being read in the session in which it was sent in, the Author was permitted by the Council to withdraw it for publication, in 1841, in the form in which it is now so well known, as a trustworthy, and almost the only text-book on the subject of which it treats. The erection, at Old Ford, of the engine from Cornwall was soon followed by a new and much larger one, upon the same principle, which the directors, out of respect to their Engineer, named the 'Wicksteed.' The applicability of the Cornish engine to the purposes of waterworks being now fully established, several large engines upon this plan were erected for the various water companies about London, under the direction of Mr. Wicksteed.

The principal additions to the reservoirs and other works of the East London Waterworks Company carried out by Mr. Wicksteed were those needed to remove the source of supply from Old Ford, on the tidal part of the river Lee, to Lee Bridge above the influence of the tide. They consisted of an open canal about 2 miles long, crossed by several occupation bridges; a cast-iron main 3 feet 6 inches in diameter, laid under the bed of the river; and a reservoir about 14 acres in extent for compensating certain tidal mills affected by the Company's abstraction of water above them. This reservoir adjoined the tideway at a point where the rise at each flood was small and of short duration; in consequence of which the openings from the river into it had to be designed so as to enable it to receive as much water as possible during the short period of flood, and to discharge its contents rapidly towards the end of the ebb. These purposes were acomplished—First, by putting down a pair of self-acting flood-gates, 30 feet wide, opening into the reservoir at the end nearest the rising tide, allowing the water to flow in freely, and closing by the first reflux of the stream, so as to impound all that had passed in. Secondly, by the construction of three exit channels each 38 feet wide at the end where the compensation water had to be discharged, each fitted with a pair of balanced gates. Each leaf of each pair of gates was 20 feet in width, fixed upon a vertical shaft, or axis, placed exactly in its middle, and opened or shut by means of a quadrant rack and pinion placed horizontally on the upper framework of the gate and worked by hand. When closed each pair pointed inwards to the reservoir, their meeting posts coming together at an obtuse angle in the centre of the channel, and their outer posts shutting against the hollow quoins of the masonry on either side. A vertical shaft, with eccentric cams placed in each hollow quoin, was then turned round so as to jam each outer post against the quoin and tighten each leaf against its iron sills and the opposite gate. The gates being evenly balanced on their central axis, were capable of being easily opened when the pressure of water was on one side, as would occur when the reservoir was full and the river low. The entire operation of opening all the six gates could consequently be performed at any time by one man, with great quickness and ease. Mr. Wicksteed also reconstructed the Lee Bridge Mills and the Stratford Mills, in order to adapt them for pumping water to the East London Waterworks Company's district.

Between the years 1838 and 1845, while still Resident Engineer to the East London Water Works, Mr. Wicksteed became the Consulting Engineer to the Grand Junction, Vauxhall, Southwark, and Kent Waterwork Companies, and carried out extensive additions to their several works, being thus, at one time, Engineer to five out of the then nine London Water companies. During the same period he constructed new waterworks at Hull and Wolverhampton, and made considerable additions to those at Brighton, and subsequently to those at Scarborough. He was also consulted by, and made Reports upon the waterworks of the towns of Leeds, Liverpool, Dewsbury, Lichfield, Leamington, Cork, Kingston in Jamaica, Valparaiso, Boston, in the United States, and other places. In 1841 he was consulted by Major Baeyer, on behalf of the King of Prussia, upon the waterworks and sewerage of Berlin, and received a gold medal and autograph letter from the King, in acknowledgment of the value of his Report. He was also, about the same period, consulted by the Pacha of Egypt in reference to the barrage of the Nile.

Having been led to investigate the questions of the sewerage of towns, and the disposal of the sewage, he, in 1845, began to experiment upon the use of lime for disinfecting sewage, assisted by the best chemical opinions he could obtain, namely, those of Mr. Aikin and Dr. Alfred Swaine Taylor. In 1847 he became the Engineer to the London Sewage Company, formed for the purpose of purifying the sewage of London, and manufacturing manure therefrom. The Parliamentary plans for an intercepting sewer along the North bank of the Thames, to a pumping station and reservoir at Barking Creek, in conformity with his views, were prepared and deposited by him for the company; but the scheme required more capital than, in the state of the money market, could then be raised, and the company was subsequently dissolved. To Mr. Wicksteed is, however, due the inception of the idea of constructing an intercepting sewer parallel to the Thames, at a depth below all the existing sewers, and the creation of an adequate fall, by artificial pumping at its outlet. He had previously, in 1841, proposed the same plan for Berlin, and subsequently both proposed and executed the design at Leicester. Following up his idea of purifying the sewage of towns, and making valuable manure from it, he succeeded at length in forming a company for this object, called the Patent Solid Sewage Manure Company. So much time and attention did he devote to this business, that he, being sanguine of success, eventually gave up his connection with all the London water companies, resigning his post as Engineer to the East London Waterworks in 1851.

The Patent Solid Sewage Manure Company, acting under his advice, established their works at Leicester, and carried them on for some years with success so far as the purification of the sewage was concerned—the River Soar being restored to nearly its pristine purity—but without the same good fortune in the production of saleable manure. Large quantities were produced; but the quality was not strong enough to compete with other manures already used by farmers; so that eventually the works failed commercially, and were given up by the company to the corporation of the town, who, however, continued to use them for purifying the sewage. Mr. Wicksteed, besides carrying out a complete system of drainage for Leicester, was consulted on the sewerage of Leeds, Leamington, Maidstone, and Scarborough; and gave evidence before the Special Committee on the Sewage of the Metropolis; but his health had been affected by the want of success in his sewage scheme at Leicester, and he was therefore retiring from professional practice, when, in 1865, he had a slight attack of paralysis, and gradually failing afterwards, he gave up work altogether.

Mr. Wicksteed strenuously upheld the several views he entertained upon professional subjects that were matters of controversy during the active portion of his career, especially in connection with waterworks and sewerage. In addition to his advocacy of the Cornish Engine for waterworks' purposes, he became known as one of the foremost supporters of the system of distribution designated as the "intermittent supply," against "constant supply;" and he contended for his opinions in reference thereto by means of arguments drawn from his practical experience in the management of some of the largest waterworks in the kingdom. He also strongly opposed the "irrigation" methods of purifying and utilizing sewage, as extravagant in their cost and profitless in their results. In designing sewers for the drainage of towns, he was one of the first to advocate the necessity of taking into consideration the ordinary rainfall upon the district to be drained, before determining the dimensions of the sewers, and he objected, on the one hand, to the theoretical conclusions of those who had promulgated the notion of using very small tubes, just capable of carrying off the actual refuse water, while, on the other hand, his love of economy in construction led him to discard the older fashion of making all drains large enough to be traversed by workmen. Above all, he upheld the opinion that an Engineer should so plan the works entrusted to his care that they might prove either reasonably remunerative or permanently useful, and he looked with little favour upon engineering projects whose chief merit consisted in their monumental appearance.

Mr. Wicksteed was elected a Member of the Institution on the 7th of February, 1837. He was a contributor of several Papers on the Cornish engine, which appeared in the Transactions and in the first volume of the Minutes of Proceedings, and for which he received a Telford medal in 1839. He had a seat on the Council from 1840 to 1843, but for many years before his death he had ceased to attend the meetings and to take part in the discussions.

Mr. Wicksteed's energy of character was remarkable, and he would frequently spend a considerable portion of the night in writing reports, and devising engineering details. He was generous and liberal to those about him, and, although at times somewhat variable in his manner towards his dependents, and impatient of contradiction, he was always pleased to further their prospects. With him there were no half measures; and if he advocated a man at all, he did so with all his heart and powers. He died at Headingley, near Leeds, on the 15th of November, 1871, aged sixty-five years.

MR. THOMAS BRASSEY,—the son of John Brassey, of Bulkeley, in Cheshire, who occupied land there which had been held by his ancestors for a couple of centuries,—was born on the 7th of November, 1805, at Baerton, near Chester, and received his early education at a school in that city. At the age of sixteen he was articled to a surveyor named Lawton in the same place, by whom, on the termination of his apprenticeship, he was taken into partnership. Among other surveys on which he was engaged about this time was that of the road between Machynlleth and Aberdovey. He now married Miss Harrison, of Birkenhead, and shortly after undertook the entire charge of the business hitherto carried on by the firm of Lawton and Brassey, and established limekilns and brickyards, and contracted for and executed a road from Tranmere to Brownborough. It thus happened that when, in 1835, the late Mr. Joseph Locke, M.P., Past-President Inst. C. E., was appointed Engineer of the Grand Junction railway, Mr. Brassey came forward and undertook a length of 10 miles of this line, known as the Stafford contract, and completed the work with advantage to himself and to the satisfaction of the engineer. He next undertook some large contracts on the London and Southampton railway, employing as many as three thousand men, and at the same time became contractor for portions of the Chester and Crewe, the Manchester and Sheffield, and the Glasgow and Greenock, railways. In 1840, some of the directors of the London and South Western railway, with a few French capitalists, formed a company for the construction of a railway from Paris to Rouen. Mr. Brassey, in partnership with Mr. Mackenzie, secured the contract for the line, although the tender he sent in was at such a price as he believed would entirely throw him out; nevertheless it was the lowest. The authorities could not suppose it possible that he could execute the works at the price; but he did, and realised a handsome profit on the transaction. Between 1844 and 1848 Messrs. Brassey and Mackenzie contracted for the Havre and Rouen, and five other French railways, and the former also undertook, in whole or in part, the works for three lines in Scotland, and two lines in England and Wales. At this time Mr. Brassey had in his employ no fewer than seventy-five thousand men; his payments for labour were from £15,000 to £20,000 weekly, while the capital involved in these contracts was about £36,000,000. Among these works may be mentioned the Caledonian railway, and a little later, the Welwyn viaduct of the Great Northern railway. In 1851, Mr. Brassey commenced works in Shropshire, in Somersetshire, and in the county of Inverness. In 1852 he undertook in Belgium, in Holland, in Prussia, in Spain, and in Italy, the lines of the Sambre and Meuse, the Dutch-Rhenish, the Barcelona and Mataro, and the Maria Antonia railways. In partnership with Messrs. Peto and Betts he constructed the Grand Trunk railway of Canada, and between 1853 and 1857 he made six more railways in France, as many in Italy, and the Bilbao and Miranda line in Spain, besides undertaking contracts in Norway, Sweden, Denmark, and Switzerland, and the railway over the Mont Cenis Pass. In Turkey and Austria he engaged in extensive contracts. In India he constructed a great part of the East Indian railway, the Calcutta and South Eastern, and other works; in Australia several hundred miles of railway; he contracted for the first railways projected in South America; and one of his last undertakinga was a contract for docks at Callao, which had to be carried out by his executors. The Barrow docks and Runcorn viaduct were among his most important enterprises. By means of subsidiary or private undertakings he constructed an enormous plant, which ministered to his home and foreign contracts. Coal-mines, iron-works, dockyards, the great establishment on the margin of Wallasey Pool at Birkenhead, 'Canada Works,' where the Victoria Bridge for the St. Lawrence was constructed, all owed their existence to his energy. The railway contracts executed by Mr. Brassey and his various partners, from 1848 to 1861, extended over 2,374 miles, and amounted to a total value of £28,000,000. The systematic and orderly execution of works to so vast an amount as those undertaken by Mr. Brassey, brought him a large amount of wealth. It is not to be supposed, however, that no reverses occurred. Never elated by prosperity, Mr. Brassey met loss with composure, and without attempting to throw it upon others. When the Barentin viaduct, on the Rouen and Havre railway 100 feet high, and consisting of twenty-seven arches of 50 feet span, collapsed in 1846, he rebuilt the bridge at his own expense, although not responsible for the failure. Again, he regularly paid a sum of £14,000 half-yearly for a line of railway, from the construction of which he had received no pecuniary advantage whatever, but for which he had guaranteed the interest for a certain time.

The nature of the relation which subsisted between the engineer of a public company and the contractors who undertook the execution of the works was, at the commencement of Mr. Brassey's career, very different from that which subsequently obtained. The early contractors were, for the most part, men of strong natural abilities, insight into the cost and method of executing work amounting to instinct, low tastes, violent habits, and grasping tenacity of purpose. A contract being once made, it seemed to be regarded as natural that the contractor should set his wits to work to make the most of it. This was to be done, on the one hand, by grinding his labourers under the pressure of the truck system and the "tommy shop," and on the other hand by "scamping" his work. Under the three grades of engineers ordinarily engaged ranked an array of inspectors. These were men set to watch that the requisitions of the specifications were not eluded, that the mortar had the proper proportion of fresh lime, that bats were not used in place of bricks, that spruce was not substituted for larch in the fencing, and so on. Very frequently these men began by displaying extreme severity, greatly to the cost of the contractor. As a rule, vexatiously minute inspectors were open to bribes. They gave trouble unless they were bought off. This matter once arranged, the less scrupulous contractors and sub-contractors often drove a roaring trade, the engineer being sold by his own watchmen. Against this system of scamping and of bribery Mr. Brassey was one of the first to make a stand. In all questions that he was called on to decide, he had the wholesome habit of inquiring "how the thing would look if it came before twelve men in a box." Bribing and scamping being thus discarded, Mr. Brassey adopted a method of his own of dealing with the engineer. It was his plan,—using an expression now perhaps forgotten,—to "smother the engineer." This smothering, however, consisted only in extinguishing all just causes of complaint. To do his work fairly and faithfully, to render inspection superfluous, and thus to annihilate the power of the inspectors, was the system which led to the attainment of such a character of reliability for the performance of work as proved to be one main element of Mr. Brassey's extraordinary success.

With a man of this nature, the relations of an engineer soon became more confidential than was at all ordinary in the early days of English railway work. His character was established by the first contracts which he executed under Mr. Locke on the Grand Junction railway, while the influence of that engineer was enormously increased by the practical backing afforded by Mr. Brassey, as an estimate by Mr. Locke meant a price at which Mr. Brassey would tender. In some instances, indeed, the support thus given to what was no longer mere scientific opinion, rendered Mr. Locke rather a dangerous adviser for his brother engineers to call in. On one considerable line of railway, as to which, in 1837, there was a question of prosecution or abandonment, the engineer appealed to Mr. Locke to support estimates which afterwards proved to be grossly inadequate. The report took the form of condemning the details of the estimate, but intimated that for the gross sum contractors might be found to execute a well-devised line between the points. The engineer in question narrowly escaped having to pay a very heavy price for the support which he thus invoked. At no part, however, of Mr. Brassey's career has he been accused of endeavouring to take the bread and cheese out of a brother contractor's mouth.

The modest taste of Mr. Brassey led him to shun distinctions which many other men so anxiously seek. However, the Government of France acknowledged his services in constructing the railways of that country by the Cross of the Legion of Honour. The King of Italy evinced his sense of the value of Mr. Brassey's labours in that country by sending him the Cross of the Order of St. Maurice and St. Lazarus. The Austrian Emperor bestowed on him the rare distinction of the Order of the Iron Crown, a decoration never, it is said, before conferred on a foreign subject. Mr. Brassey probably valued still more highly the testimonial presented to him, in 1851, by his numerous agents, sub-contractors, and tradesmen, which cost £10,000.

Mr. Brassey rose to the unquestioned leadership of his calling by the possession and the exercise of qualities which are not only, in the degree in which he possessed them, rare in themselves, but which are still more rare in combination. His character presented a happy equilibrium between forces of opposite tendency. He was remarkably keen and sagacious in perceiving and in maintaining his own interest, at the same time that he was unimpeachably just with regard to the interest of others. He was eminently kind-hearted, at the same time that he was quite deaf to the voice of wheedling. He undertook, and carried out, not a few large operations, rather for the sake of the employment of his dependents than for his own emolument; and he largely increased his wealth by so doing. He was bold to audacity in the magnitude of his operations, at the same time that he was cautious, even to timidity, in the preliminary investigation of details. Fully conversant only with the English language, and making no pretension to a critical acquaintance with that, he not only so expressed himself as invariably to avoid misconstruction or confusion, but found himself almost as much at home in the principal Continental capitals as he did in London. Modest and unassuming in his manners, he was yet fully aware that he was an industrial power of the first magnitude. Liberal, on a large scale, in his dealings with the public companies for which he executed such wholesale works, he was exact to the utmost minuteness as to the regularity of certificate and of payment. He was at once generous and exact, energetic and calm. While ever to be found at the spot when his presence was required, he was free from that drive and bustle by which some persons endeavour to hurry their subordinates, and to obtain the reputation of men of business.

Mr. Brassey was straightforward, prompt, and honourable to the last degree; he had a frank, hearty address, a cheery voice, and a pleasant smile; he was tall and strong-built, but spare. He left three sons, of whom two are in Parliament, and the youngest in the army. He was elected an Associate of the Institution of Civil Engineers on the 13th of January, 1852, served on the Council in the year 1853, and died, of bronchitis, at St. Leonard's-on-Sea, on the 8th of December, 1870, aged sixty-five years.[1]

MR. **SAMUEL THOMAS COOPER**, the elder son of Mr. Cooper, of Worsborough Hall, near Barnsley, and of the firm of Messrs. Cooper, Field, and Hood, the founders of the Leeds Iron Works, Leeds, was born at Worsborough in June, 1831. He commenced his business career at an early age in connection with the Leeds Iron Works, of which he subsequently became the principal partner, and in that capacity was doubtless known to many members of the Institution. After having taken an active part in the management of the concern for nearly twenty years, in 1865 he retired, though still retaining his interest in the firm, to a property he had purchased—Bulwell Hall, Nottinghamshire—where he afterwards principally resided, and where he died suddenly from an attack of apoplexy, on the 10th of February, 1871. He was also a partner in the Worsborough Cold Blast Iron Company and the Silkstone and Worsborough Collieries near Barnsley, and was an active magistrate for the county of Notts.

He was a member of the Institution of Mechanical Engineers, and hospitably entertained the members at his residence on the occasion of their visit to Nottingham in 1870. He was elected an Associate of the Institution of Civil Engineers on the 21st of May, 1867.

LIEUTENANT-GENERAL SIR **WILLIAM DENISON, K.C.B.**, was the third son of the late John Denison, Esq., of Ossington, in the county of Notts, and was born at his father's house in London, on the 3rd of May, 1804. After being under education at Eton for four years, he was removed thence at the comparatively early age of fourteen, in order to enter on a course of more special training for his future profession. He attained a good place at Eton in proportion to his age; but this he always declared was more owing to the excellent training he received at home, and from his private tutor (the Rev.

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[1] This memoir has been compiled chiefly from the "Builder." A most interesting volume, "Life and Labours of Mr. Brassey, 1805–1870," by Sir Arthur Helps, K.C.B., has since been published.—Sec. Inst. C.E., July, 1872.

C. Drury), than to any great exertion of his own. His account of himself during those early years is, that at that time he had no particular aptitude or inclination for study, and did no more than he was obliged to do. When he was about fifteen, however, the study of mathematics, hitherto a mere task, began really to engage his attention: his mind, as he described it in after-life, seemed to open to the results of such study, which, thenceforth, became a favourite pursuit with him, and a line of study which he earnestly recommended in after-years to other young men. He entered the Royal Military Academy at Woolwich in February, 1819, and passed the examination for a commission in December, 1823; but, as no commissions were at that time given in the Royal Engineers, and he preferred waiting for one to joining any other branch of the army, he was not gazetted as a second-lieutenant till March, 1826. In the spring of the following year he was ordered to Canada, where, for the next four or five years, he was employed, with a company of Sappers, in the construction of the Rideau canal, which had then just been commenced. Accounts of this work, including the Hog's-back dam across the Rideau river, may be found in the "Professional Papers of the Corps of Royal Engineers"—a publication which was suggested by him, which was mainly established by his exertions, and which he continued to conduct as editor, from the appearance of the first volume in 1837, till he left England for Van Diemen's Land in 1846. The value of the service thus rendered to his corps is fully understood by his brother officers; and their appreciation of it may be seen in the maintenance of the publication,—a volume having been published annually ever since. It was during these years in Canada that his connection with the Institution of Civil Engineers may be said to have commenced; for, in the intervals of his other duties, he, in the years 1830 and 1831, made a series of experiments on the strength of various kinds of American timber, principally undertaken with a view of establishing some common standard of comparison between the woods in general use in England and in America. The results of these experiments were communicated to the Institution in 1837,[1] in which year he was elected an Associate; and a Telford Medal was awarded to him for this communication, which the Council, in their Report for 1839, referred to as an example to other military engineers, of the valuable services which their opportunities would enable them to render to Civil Engineers. His return to

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1837), p. 26; Transactions Inst. C.E., vol. ii., pp. 15-32.

England at the end of the year 1831 put a stop to these experiments, and prevented the carrying out of others on a larger scale. He was then for several months stationed at Woolwich; and this was the only portion of his life during which he was occupied with the purely military duties of his profession. He was always selected for some special service, and these duties were very various. It was an axiom of his that an officer of Engineers should be fit for work of any kind; and his own career was a remarkable illustration of this principle. With the exception of the Foreign Office, there is hardly a single department of the Government under which his services have not been engaged. It should be mentioned, also, that all these varied employments came to him unsought. Two disappointments in early life—in not obtaining posts which he had desired, led him to form a resolution that he would never again ask for any appointment, but would take what was offered to him. He was wont to say that this resolution originated in something of mortified pride, but it was certainly persevered in afterwards on a higher principle—that of a belief that it is best to leave the ordering of our lot in life to a higher and wiser Hand than our own. In February, 1833, he was ordered to Chatham, to undertake the duties of instructor in surveying to the cadets about to obtain commissions in the corps of Royal Engineers. He continued at this post till the summer of 1835, when he was appointed a member of the Corporation Boundary Commission; and after the completion of that duty, in 1836, was employed for a short time in making observations with Ramsden's zenith sector, and in comparing it with the mural circles of the Royal Observatory, at Greenwich. In the autumn of 1837 he was placed in charge of the engineering works in progress at Woolwich Dockyard—Captain Brandreth, R.E., being at that time the Director of Works to the Admiralty; and he continued for the next eight years in the employment of the Admiralty, superintending the works first at Woolwich; in the summer of 1842 being sent to inspect the Admiralty Works at Bermuda; and in June, 1845, he was transferred to the Portsmouth Dockyard. While at the former place, he also furnished the plans for, and superintended the construction of, the new barracks for the Royal Marines; and, in the intervals of these avocations, found time for work as a member of another Government Commission on the Health of Towns. In 1838, he served as an Associate-Member of the Council of the Institution of Civil Engineers—he and the late Mr. W. Carpmael being the first representatives of that class on the Council.

In the spring of 1846, much difficulty having arisen in the management of the large convict establishment in Van Diemen's Land, the Secretary of State for the Colonies (the Right Hon. W. E. Gladstone, M.P.) applied to Sir John Burgoyne, the Inspector-General of Fortifications, to select an officer of talent and energy from the corps of Royal Engineers, for the important post of Governor of that colony. Captain Denison was specially recommended for the service, was accordingly appointed, and at the request of Lord Auckland, the First Lord of the Admiralty, received the honour of knighthood. He left England in October of that year, and arrived at his new post on the 25th January, 1847. From henceforward his duties may be said to have been political and social, rather than professional; but still his engineering knowledge, and the experience acquired during his previous career, proved highly useful, in a variety of ways, both to himself and others. It enabled him to suggest and originate many useful works; besides which, the Engineer Governor was soon found to be a valuable referee; and his opinion and advice were frequently asked, and always readily given,—now as to the foundations of a church,—now as to the drainage of a town.

Towards the close of 1854 he was appointed Governor of New South Wales, which post he held for the next six years. Here, as in Van Diemen's Land, the period of his government was marked by important political changes. In both he had to inaugurate and watch over some of the first phases of representative institutions and responsible government; and in Van Diemen's Land he had, for a time, to encounter considerable difficulties, arising from the opposition in the colony to what was at that time the policy of the Home Government with respect to the transportation of convicts.

In November, 1860, Sir William Denison was informed that he had been appointed to the Governorship of Madras; and he was directed to proceed thither as speedily as possible, and told that he would find his commission awaiting him there. Accordingly, he made his arrangements for the change with all possible despatch,—arrived at Madras, and was sworn in on the 18th February, 1861. There he found the Government still in a sort of transition state, consequent on the recent transfer of authority from the East India Company to the Crown: much was still unsettled relative to the details of the Government in the different Presidencies, and the relations of these to the Supreme Government at Calcutta. The subject of the reorganization of the native army, too, was just beginning to occupy attention; and all these unsettled questions added much to the amount of occupation thrown upon him on his first arrival. He found leisure, however, for the consideration of two engineering schemes which were soon pressed upon his attention, and which involved a visit to each locality. The first of these was for the improvement of the navigation of the river Godavery; the second, for the formation of a harbour at Sedashegur, on the west coast of the Peninsula.

In November, 1863, he was called upon, in consequence of the death of Lord Elgin, to assume temporarily the office of Governor-General, until a new one could be appointed from home. This appeared likely to be no easy position: to say nothing of an accumulation of business, which had been necessarily left in abeyance during Lord Elgin's illness, there was a war raging on the north-western frontier, which had begun to assume a very unsatisfactory aspect. An expedition had been set on foot by the Lieutenant-Governor of the Punjâb, and agreed to, somewhat unwillingly, by Lord Elgin, against the fanatical tribes inhabiting Sitana and the Mahabun Mountain; but the march against these enemies, through a country little known, had proved more difficult than was expected; other hill-tribes, taking alarm at the approach of the British troops, made common cause with the 'Sitana fanatics,' and vigorously attacked our forces; and at length the Government of the Punjâb, taking alarm, had recommended, and the Council at Calcutta, partaking of the panic, had concurred in a recommendation, that our troops should be withdrawn to the plains—a virtual acknowledgment of defeat, which, in Sir W. Denison's opinion, could not but have a most injurious effect on the future tranquillity of the frontier, and on the prestige of the British name.

It was no wonder, under these circumstances, that the congratulations of Sir William's friends at Madras, on the splendour of his new position, were mingled with some expressions of fear lest he should suffer from the weight of toil and responsibility thus imposed upon him. His own remark on these expressed fears was characteristic: "I do not," he observed to a member of his own family, "quite enter into what they say about my great responsibility. My responsibility is no greater than it always has been;" and, on some surprise being expressed at these words, he added, "No! I was equally bound before to do my *very best*—and I can do no more now." Simple words, but expressive of a truth which, if considered, would save many a mind from an almost overwhelming burden of anxiety—namely, that we are not answerable for the results of our work; that our responsibility extends only to the carrying through of that work, be it what it may, with thorough integrity of purpose, and bringing to bear upon it the very utmost of our energy and ability. The principle here expressed was certainly well exemplified throughout Sir W. Denison's career. Duty was duty to him; and whether the task of the moment was the government of an empire or the construction of a plan, it was carried out with the same thoroughness of purpose—he felt "equally bound to do his very best." His 'best,' on the present occasion, was blessed with eminent success. His first effort on arriving at Calcutta was to induce the Council to rescind the order for the withdrawal of the troops, and to recommend, instead, a movement in advance. He succeeded in carrying this recommendation through the Council, though with considerable difficulty, and in the teeth of a protest from one of the members; and the result of the bolder course advocated by him, and ably and gallantly carried out by Sir Hugh Rose (now Lord Strathnairn), and the officers and troops under his command, was, that in three weeks' time the war was at an end, every point in dispute gained, and the whole frontier tranquillised. Sir John (now Lord) Lawrence, the new Governor-General, who was sent from home with all possible speed, under the impression that his former experience in the Punjâb and on the frontier rendered him the fittest man to deal with the emergency, found on his arrival—and acknowledged that he found—the work ready done to his hand.

Sir William Denison returned to Madras about the middle of January, 1864, and the remainder of his term of office there passed without any remarkable event; but his affection for his old corps evinced itself strongly when, in the autumn of 1865, he was asked from the Horse Guards whether it was his intention to return to the active list of his corps or to retire, as the term of years during which he had been 'seconded' for special services had expired. "It was not his intention to retire," he said. He would sooner have given up his position at Madras, honourable and lucrative as that was; and he wrote home accordingly, expressing his readiness to return at once to the duties of his corps, if ordered to do so; but at the same time requesting that, unless his services were specially required, he might be allowed to remain to complete the regular term of office at Madras. This request was acceded to; but he wrote to the Secretary of State for India, stating his wish to be relieved as soon as that period should have expired. Accordingly, his successor, Lord Napier, arrived at Madras on the 27th March, 1866, and Sir William Denison, with his family, embarked on the following day for England. He remained for about ten days in Egypt by the way, occupied in examining the works, then in progress, of the Suez Canal; and a Paper by him on this great work was communicated to the Institution of Civil

Engineers,[1] and the Watt medal was awarded to him in consequence.

Sir William arrived in England on the 28th May, 1866, and about a year afterwards was offered the command of the Royal Engineers at Portsmouth. His hearty love of his profession made him gladly accept this offer; but his Royal Highness the Commander-in-Chief eventually expressed an opinion that it was not advisable for one who had held so much higher positions to accept such a comparatively small command, and the appointment did not take place. Sir William's letter, in reply to this decision, addressed to the Inspector-General of Engineers, expresses in warm terms his affection for his old corps:—

"United Service Club, 1st July, 1867.

"MY DEAR SIR JOHN,

"I am much obliged to you for allowing me to see his Royal Highness's letter on the subject of my appointment as Commanding Royal Engineer at Portsmouth. I feel grateful to his Royal Highness for the testimony borne by him to the mode in which I have performed the duties incidental to the various positions in which I have been placed. I cannot but think, however, that the motives which have actuated me throughout my career have been misunderstood, and feelings alluded to as likely to arise out of the inferiority of my present position, or of my possible future one, to those which I have held, which neither have found, nor will find, a place in my mind.

"I have always had a strong corps feeling, and have ever considered my position as an officer of Engineers an honourable distinction. I have done my best to qualify myself for the various duties which, as an officer of Engineers, I might be called upon to perform; and I have striven to incline my brother officers to take the same view as myself of the very varied character of their duties. How varied these have been in my own case you knew very well; but the variety was not the result of any application on my part. The offer of employment, other than that of the ordinary duties of the corps, in every case came spontaneously from persons in authority; and I accepted the offer, feeling myself competent to execute the works intrusted to me, and with a conviction that in so doing I was but acting up to my duty as an officer. I never looked upon the appointments I held as permanent; indeed they were essentially of a temporary character; and, though I have been moved from one government to another, I have always looked forward to the time when I could rejoin my corps, and, as a matter of course, reassume my military position. His Royal Highness is aware that in 1865, when the question was put to me whether I intended to resign my commission, I distinctly stated that such was not my intention, and that I held myself in readiness to obey any orders I might receive from his Royal Highness. I did not then, neither do I now, think that in reassuming my position as a Colonel of Engineers, after having acted as a Governor or Governor-General, I have in any way lost caste; or that, in performing the duties incidental to an officer of my rank and standing I can be considered to be doing anything derogatory to myself. On the contrary, I feel that a refusal on my part to accept the realities of my position, and to perform my duties as an officer, would be equivalent to an admission that I was incapable or unfit to do so; and this, most certainly, I am not in any way disposed to allow. My opinion is that, in returning as a matter of course to my ordinary duties in the corps, I have but acted in accordance to a sense of duty, and as I should wish to see my brother officers do. That they appreciate my motives, and are glad to see me back amongst them, I have every reason to believe. Such being my feelings, and those of my brother officers, I, when asked by the Deputy Adjutant-General whether I would accept the command at Portsmouth, replied at once in the affirmative; indeed I could not act otherwise; and I trust that his Royal Highness will admit that, under the circumstances, no option was left to me, and will appreciate my wish to resume my military duties.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi., pp. 442-476.

"Believe me,
"Yours very truly,
(Signed) "W. DENISON."

In the spring of 1868 Sir William was appointed Chairman of a Royal Commission for inquiring into and recommending measures to prevent the pollution of rivers, by the various manufacturing and mining processes carried on in different parts of the country; and in this occupation he continued actively engaged up to the time of his death. At the annual meeting of the Institution of Civil Engineers in December, 1868, Sir William Denison was again elected an Associate-Member of Council, and he served in that position during the following year. His leisure hours were partly occupied in plans for colonization, and other objects tending to promote the welfare of the professional and labouring classes; and some lectures which he had promised to give on those subjects were only prevented by his last and fatal illness.

A memoir like this is not the place in which to enlarge upon his inner and higher life; yet none who really knew him would think any description complete without at least an allusion to the cheerfulness and happiness which he diffused around him in his home, the Christian example which he has left as the best of all legacies to his children, and the ever-brightening faith and hope which enabled him to remark that, "As one gets older, one gets happier;" and that "the glorious prospect beyond the grave looks brighter as it comes nearer." Without some delineation of such marked features as these, no sketch of him could be recognised as a likeness.

His last illness was sudden and short; and he died at East Sheen, Surrey, on the 19th January, 1871.

MR. ARTHUR FIELD, the youngest son of Mr. William Field, of Oxford Street and Kingsbury, Middlesex, was born in London on the 18th of June, 1844.

His education was commenced at a private school, and afterwards continued under Dr. Mercer, of Darmstadt, where he obtained a sound mathematical training. He returned to England and studied for a time at King's College; and in the workshops of that Institution he picked up a considerable knowledge of applied mechanics, and of the use of tools. After leaving King's College, his education was completed by a course of reading with Dr. Smalley, of Blackheath. Having determined to adopt Engineering as his pursuit in life, he was articled, in December, 1862, to the late Mr. James Simpson, Past-President, Inst. C.E. The first three years of his pupilage were spent at the Grosvenor Road Works, Pimlico, where he acquired a thorough practical knowledge of the general construction of machinery, more especially of that connected with the pumping and distribution of water. He also had an opportunity of studying the construction of reservoirs, filter beds, and other details of water supplies on a large scale, and was besides entrusted with the superintendence of the erection of the iron bridges on the Thames Valley railway. After completing his course at the Grosvenor Road Works, he moved to Mr. Simpson's office in Great George Street, where he made a complete set of designs and working drawings for some proposed gas works. He also succeeded in carrying off the prize in a competition for designs of hunting and racing stables at Epsom.

In February, 1868, Mr. Field was appointed, from among a large number of candidates, Engineer to the Gas and Water

Commissioners of the Local Board of Widnes, near Liverpool. Various schemes for an adequate supply of water for the increasing wants of the district had been proposed by his predecessors, but none of them had been adopted, and on his succession to office he prepared an entirely original set of plans. The main feature of these was the construction of a well at Crontan, 60 feet deep and 10 feet in diameter, from which the flow of water was so great that even a few hours' cessation of pumping caused it to rise to the level of the ground. The water was lifted by a pair of condensing steam engines of Mr. Field's design; they were 50 nominal H.P. each, and worked two 16-inch pumps, with a stroke of 3 feet 6 inches, forcing the water for a distance of 2 miles through a 16-inch main to the reservoir at Pex hill, which was situated 150 feet above the level of the town, and was capable of holding 1,617,000 gallons. The service main from this reservoir was about 13 miles long, and capable of supplying 750,000 gallons of water per day, the actual quantity supplied during the year ending September, 1871, being 183,230,000 gallons. The entire cost of these works, which are most efficient, was, exclusive of Parliamentary and legal expenses, £43,803. A better proof of the activity and energy displayed by Mr. Field cannot be adduced than the fact that the designs were completed, the contracts let, and the works commenced, in less than three months after his appointment; they were opened in July, 1869, a little more than one year from their commencement. In February, 1869, he was appointed Engineer, Gas Manager, and Surveyor to the Local Board, and his first undertaking in this new capacity was to completely reorganise, and indeed almost reconstruct, the gas works which had been allowed to fall into a dilapidated condition. A new retort house containing eighty retorts, new condensers, an exhauster, two scrubbers, and two purifiers, were erected. Also, a single lift gasometer 80 feet in diameter, which, with the three old ones, gave a total storage capacity of 168,800 cubic feet. Great pains were taken by Mr. Field in re-arranging the whole of the service pipes, and in preparing accurate plans of their positions which had, up to that time, been neglected. The works are now capable of producing 300,000 cubic feet of gas per day. The total supply during the year ending September, 1871, was 23,225,980 cubic feet. The cost of this extension of the gas works was £15,078.

At the end of the year 1870 he resigned his office of Engineer and Surveyor to the Local Board, and commenced to practise in Liverpool, being however retained by the Local Board as their

Consulting Engineer. He rapidly succeeded in forming the nucleus of a remunerative practice, and was soon engaged in the construction of a large reservoir in Portugal; and having given special attention to the construction of the apparatus and machinery required by chemical manufacturers, he was occupied up to the time of his decease in designing some extensive plant of this description.

He died of typhoid fever on October the 20th, 1871, at Kingsbury Cottage, Appleton, near Widnes, sincerely regretted by all who knew him. He was remarkable for the energy he displayed in carrying out whatever he undertook. He was ever ready to impart information to his professional brethren, and his bearing to his subordinates was distinguished as being truly gentlemanlike. He was much loved by a large circle of private friends, and always retained the estimation and liking of the many professional acquaintances he made in the course of his brief but useful and promising career. He was much addicted to field and athletic sports, and in Lancashire became the Secretary of the Farnmouth Athletic Club, which, under his management, acquired considerable local celebrity. He married on August the 9th, 1871 (only ten weeks before his death), the daughter of Mr. Edward Young, J.P., of Birchfield, Rainhill, Lancaster.

He was elected an Associate of the Institution of Civil Engineers on December the 7th, 1869, and bid fair, on account of his increasing professional reputation, to become a prominent member.

MR. JOSEPH FREEMAN, the eldest son of Mr. William Freeman, of Millbank Street, Westminster, was born on the 6th of November, 1819. Upon leaving school he was for some years with his father, but eventually became engaged in the iron trade, to many of the members of which he was well known. For the last twenty years he had been the valued representative in London of the Low Moor Iron Works, near Bradford, Yorkshire, and his loss was deeply deplored by the partners in and all connected with those works. He was elected an Associate of the Institution on the 7th of May, 1850, served on the Council in the Session 1865-6, and died at his residence, North House, Clapham, on the 26th of February, 1871, in the fifty-second year of his age.

MR. SAMUEL TATE FREEMAN, the fifth son of Mr. William Freeman, of Millbank Street, Westminster, was born in London on the 7th of August, 1827. He was articled in June, 1845, to Messrs John and Alexander Gibb, at that time the Engineers of the Aberdeen railway. Under them he had charge of a portion of the line from Aberdeen to Stonehaven. When Messrs. Gibb resigned that appointment Mr. Freeman's indentures, with their consent, were transferred to Messrs. Locke and Errington, under whom he continued to superintend the works of the Aberdeen railway till the completion of the line. In November, 1851, he commenced to practice on his own account in London, and surveyed several lines of railway for Messrs. Locke and Errington. In 1854 he entered into partnership with Messrs. Henry Lee and Son, contractors, in a contract for making the Birkenhead Graving Docks. On the completion of these works, in 1856, he again entered into partnership with the Messrs. Lee, for the construction of a portion of the Dumfries and Castle Douglas Branch of the Glasgow and South Western railway, from Dumfries to near Dalbeattie. In 1861, with the same firm, he undertook the Lanark branch contract to Douglas, including a large bridge over the Clyde; and in 1863 a branch line of the Caledonian railway from Glasgow to Rutherglen, the Perth Viaduct, and the Leith Branches railway. On the completion of these works he went to Holland, and there engaged, jointly with the Messrs. Lee, in carrying out the new Amsterdam Canal, Messrs. Hawkshaw, Waldorp, and Dirks being the Engineers. The portions of the work which he undertook were the excavations, the formation of the banks in the lakes, dredging, the construction of the large sea locks at the North Sea entrance, and the reclamation of land. To expedite the dredging operations, Mr. Freeman, assisted by Mr. Burt, introduced a system by which the dredged material was disposed of by being pumped through floating pipes. This plan proved such a success that Sir Charles Hartley, M. Inst. C.E., Engineer to the European Commission of the Danube, adopted it in dredging the Sulina mouth of that river, and with the most satisfactory results.

Mr. Freeman married, on the 30th of December, 1851, Mary, third daughter of Colonel Martin Lindsay, C.B., late of the 78th Highlanders, by whom he had eleven children, and of these six sons and two daughters survived him. He was elected an Associate of the Institution on the 6th of February, 1866, and died at the age of forty-four, on the 8th of November, 1871, at his residence "Meer en Bosch," Heemstede, near Haarlem, Holland, suddenly of heart disease, which he had contracted when on the Aberdeen railway from a blow by a piece of granite. He was a devoted father, a kind friend, and a generous master, and was universally loved and respected, by all who had the privilege of knowing him, for his just, amiable, and sincere Christian qualities.

MR. CHARLES FRODSHAM was born on the 15th of April, 1810. He was the third son of Mr. W. J. Frodsham, chronometer maker, who, while devoting himself to the higher branches of his own art, took an active part in the promotion of general science, and attained the honour of admission as a Fellow of the Royal Society. Mr. Charles Frodsham was brought up to his father's business, having been apprenticed to the firm of Messrs. Parkinson & Frodsham; and after continuing the same pursuit on his own account for several years, became the successor of Mr. John R. Arnold. In early manhood he showed a remarkable faculty for undertaking the more minute and intricate calculations involved in the construction and regulation of chronometers, which led him in later years to discover the true cause of the error in the compensation balance. This discovery proved to be of immense practical utility, as it substituted at once the precision of mathematical formulæ for the doubtful technicalities and uncertain rules hitherto practised. On the 7th of April, 1846, Mr. Frodsham was elected an Associate of The Institution of Civil Engineers, and in the following year, in conformity with the engagement entered into on admission, presented to the Institution a Paper "On the Laws of the Isochronism of the Balance Spring, as connected with the higher order of Adjustments of Watches and Chronometers,"[1] for which a Telford Medal was awarded to him. On the occasion of the (London) International Exhibition of 1862, Mr. Frodsham was appointed a Juror in Class XV.; and being elected reporter, he made a report to the Jury on horological instruments, which was regarded as very clever and exhaustive. He was, in the same year, the author of a pamphlet, entitled, "A Few Facts connected with the elements of Clock and Watch making," he served twice as Master of the Clockmakers' Company, was appointed a Juror of the Dublin Exhibition in 1865, and both Juror and Vice-President of Class 23 at the Paris Exhibition in 1867. He also collected materials for and commenced an exhaustive treatise on his art. Although excluded by his position, as a Juror, from competition on these occasions, he gained eleven medals, among which was the Grand Gold Medal of the Emperor of Russia. These various labours were achieved and these distinctions won in spite of ill-health and an extreme delicacy of constitution, from which he suffered through life. Mr. Frodsham was a member of the Council and Club of the Royal Astronomical Society.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. vi., p. 224.

In private life Mr. Frodsham was of a genial temperament, cheerful under bodily ailments, and well stored with general information. His death, which occurred on the 11th of January, 1871, caused deep regret to a large circle of relations and friends, by whom he was highly esteemed. In public life his name will be ever honourably associated throughout the civilized world as one of the best read and most practical of the many clever men who have been connected with the science of horology.

MR. THOMAS WILLIAM GARDNER, the only son of Mr. T. W. Gardner, of Wormley, Herts, was born in London on the 30th March, 1841. He was educated first at the school, and afterwards in the Department of the Applied Sciences, of King's College, London.

The year of his leaving he gained a mathematical scholarship, and was second in the competition for another scholarship. By the late Mr. Brunel he was introduced to Mr. Bazalgette, M. Inst. C.E., to whom he was articled in 1859, and whose first pupil he became. During his pupilage he was constantly employed on the design and execution of the works for the Main Drainage of London, and his increasing skill and energy were noticed by all connected with those parts of the undertaking with which he had to do. The northern outfall, contracted for by Messrs. Furness and Co., was especially his care. Hydraulic engineering now became his chief study, and several months were spent in Paris, in order to become thoroughly acquainted with the French system of drainage. In 1864 he was appointed engineer and assistant manager on Mr. Furness' contract for the construction of roads and sewers in Odessa; and in the complicated law proceedings against the Russian Government concerning the English work, Mr. Gardner's powers and intelligence were thoroughly proved. In 1868, on returning to England, he was for a time in charge of the contract for a portion of the Thames Embankment. Again going out to Odessa, he was intrusted with the entire management of the works there, and amid much difficulty carried them on with vigour.

In December, 1866, he was elected an Associate of the Institution of Civil Engineers, and took a warm interest in the proceedings. He was also a Fellow of the Geological Society. In March, 1869, during the general stagnation of the profession in England, he went to Calcutta, taking the appointment of Assistant-Engineer to the municipality. The works there were extensive. Mr. Gardner's duties included the entire charge of a contract for main drainage works, involving an expenditure of £60,000, and also in co-operating with the chief engineer, Mr. W. Clark, M. Inst. C.E., in the pumping station and outfall works, and those connected with the reclamation and irrigation of the Salt Water Lake. He also designed extensive works for Government House, the public offices, and the bazaars, hospitals, &c., of the city. His health, however, obliged him to leave India, and he returned with a weakened constitution to live but one more year in England. At the time of his death he was filling the post of surveyor to the parish of Hampstead, and only awaiting the revival of engineering activity to show his thorough knowledge and ability in the branch of the profession to which he was so heartily devoted.

He sunk under an attack of suppressed smallpox in his thirtieth year, respected for his integrity as well as power, and sincerely regretted by a numerous circle of friends.

MR. HENRY GEORGE HULBERT, the elder son of Mr. H. Payne Hulbert, of Bath, was born on the 23rd of May, 1839. After being educated at local schools, he in February, 1855, was articled to the firm of Messrs. Cotterell and Spackman. On the completion of his term he was engaged by them in May, 1860, as a land and engineering surveyor, near Towyn, in North Wales, and, subsequently, in making the Parliamentary survey for the extension of the Bristol and Exeter railway to Portishead. He was also engaged as surveyor, on behalf of various land-owners, of the oolitic quarries at Box and the neighbourhood of Bath, and carried out some tunnelling operations in connection with them with great precision. In 1865 and 1866 Mr. Hulbert was occupied on the Parliamentary survey for the extension of the Midland railway to Bath. On the day of the opening he caught a severe cold, which settled upon his lungs, and after lingering for two years he died at Bath on the 13th of September, 1871, in the thirty-third year of his age. Mr. Hulbert was elected an Associate of the Institution on the 2nd of April, 1867.

MR. HENRY DE LA POIRE MURPHY, the son of Mr. Henry C. B. MacMorrough Murphy, a practising solicitor in Dublin, was born in that city on the 28th of April, 1828. During his earlier years he enjoyed the advantages of a liberal scholastic education. When quite a boy he showed a tendency for a seafaring life, and was accordingly submitted to the usual training for that profession. At the age of fifteen he had completed the prescribed course of navigation and marine surveying, and then entered upon active duties in the mercantile service. Mr. Murphy followed that profession assiduously, availing himself of all the means of improvement within his reach; and, making his way upwards with steady advances, secured the confidence and esteem of his commanders and brother officers in the service. In other respects, however, his naval career was a singularly unlucky one. He was three times shipwrecked, and on each occasion narrowly escaped being drowned. In the year 1859, wearied with disappointments and discouraged by his losses, Mr. Murphy joined some relatives then resident in Bombay, and was thus enabled to enjoy a short period of relaxation, after fifteen years of almost incessant toil and exposure to the destructive influences of a tropical climate. During his residence in Bombay, Mr. Murphy was introduced to Major-General Walter Scott, then Chief-Engineer at the Presidency, who, knowing his repugnance to resume a seafaring life, and entertaining a high opinion of his executive and intellectual qualities, obtained for him an appointment on certain survey operations then being carried out in the province at Guzerat, under Captain Chambers, of the Royal (Madras) Engineers. On the conclusion of these surveys, Mr. Murphy was attached to the Bombay Harbour defence works, as nautical assistant, in which capacity he had charge of a considerable fleet of steamers, and other craft. He was also placed in charge of the extensive workshops connected with the harbour defence works; and besides reclaiming a considerable area of the shore, for the construction of boat-harbours, landing-wharves, &c., he executed a pier of some magnitude for the shipment of the stone employed in the construction of the several batteries.

In every position that Mr. Murphy held, and in all the work that he carried out as a government officer, he displayed an energy and power of organization that commanded the approval and admiration of his superiors. In cases of emergency it was no uncommon thing for Mr. Murphy to be entrusted with the performance of the required duties. During the despatch of the war and engineering materials for the Abyssinian campaign from Bombay, great difficulties were experienced in lading the transport vessels and clearing them out of port. They were, in most instances, chartered by time, and there was, therefore, little inducement on the part of the commanders to hasten their departure. Mr. Murphy was, however, detailed for the important duty of superintending the shipment of the plant, and contributed in no small degree to the success of the preliminary arrangements of the undertaking. The exposure, loss of rest, and the anxiety, however, proved too much for his long-tried constitution, and after a period of broken health he was compelled to leave India, and seek the restoring influences of a home climate. The change unfortunately proved of little benefit, and Mr. Murphy, after two years of almost constant travel through England, France, and Ireland, died in Dublin on the 6th day of April, 1871, in the 44th year of his age, deeply regretted by all who knew him.

Mr. Murphy was elected an Associate of the Institution of Civil Engineers on the 4th of May, 1869.

Mr. EDWARD PRICE was born in 1805-6 at Callow Hill, near Minsterley, in Shropshire. His father, William Price, was at that time a ganger in the Snailbeach lead mines, near Minsterley, and under him, when a boy, Edward Price acquired that knowledge of mining which in after-life proved of such great service to him. He left Minsterley when quite a lad, and started to make his way in the world with only two half-crowns in his pocket. The difficulties he encountered and the privations he endured before obtaining regular work are not known; but soon afterwards he was engaged by Mr. Mackenzie, on the works of the Worcester and Birmingham canal as timekeeper, in which situation, whilst keeping count of the number of men and horses employed and of wagons filled, he learnt the value of labour, by ascertaining from the inspectors the relative quantity of work executed. Here he saved money and conducted himself so well, that he was employed more than once to superintend jobs of work in cases of emergency. Not long afterwards he found employment in building the sewers of King William Street, in the City of London, which was then in course of construction, and in the prosecution of this work first experienced the advantage of his early training.

When the works of the London and North Western railway were in progress, he was engaged as ganger of miners at the Primrose Hill tunnel, under the contractor, Mr. Thomas Jackson; and when the contract was given up, Mr. Price continued to serve in the same capacity directly under the late Mr. Robert Stephenson, M.P., Past-President Inst. C.E. At the Kilsby tunnel he was intrusted with a more responsible position, in carrying out the mining operations there. In 1838-9, he executed a contract for earthwork, and the viaduct on the Great Western railway, at Chippenham, under the late Mr. I. K. Brunel, V.-P. Inst. C.E. In 1844, on the recommendation of Mr. Stephenson, he went to France and contracted for the construction of the tunnel at La Nerthe, on the Marseilles and Lyons railway, under M. Talabot; which work he executed within the specified term, and much to the satisfaction of his employers. Between the years 1846 and 1849 he contracted, under Mr. Stephenson and Mr. G. P. Bidder, Past President, Inst. C.E., for the construction of part of the North Staffordshire railway. In 1851 to 1854 he was engaged in Egypt, under Mr. Stephenson, in the execution of the Benha and Kaffre Azayat bridges over the Nile, and in the construction of part of the Alexandria and Cairo railway. These bridges were built on iron cylinders sunk, under the compressed air process, more than 90 feet into the bed of the river. This style of construction was then comparatively new,—none of the large bridges on the Continent since erected on similar foundations having then been constructed,—and the work required active and trained superintendence. Nevertheless, no accident of importance occurred, all impediments to the progress of the works were overcome, and they were completed within the specified term. Before these bridges were finished, Mr. Price entered into a contract with the Brazilian Government for the construction of the Dom Pedro Segundo railway, from Rio de Janeiro to the foot of the Serra S. Anna, a distance of 40 miles. In this he succeeded under most difficult and untoward circumstances, both the cholera and yellow fever raging together, and, notwithstanding all precautions, carrying off his English assistants and foremen one after another as soon as they were sent out. On the 2nd of December, 1856, after his return to England, he was elected an Associate of the Institution of Civil Engineers.

The larger chance of gain which generally attends foreign contracts, and his perfect confidence in his own powers, induced him at this time to prefer such undertakings to more certain but less speculative enterprises in England. In accordance with this view, on the conclusion of peace between the Allies of Turkey and Russia, he was induced to obtain a concession for a railway from Samsoon to Swas, in Asia Minor, but this scheme was afterwards abandoned, the traffic having been found inadequate to the charge on the large capital required for its construction. From this time forward, however, he gave his sole attention to foreign works, and many such contracts were offered to him and refused. Eventually he was engaged as contractor in the construction of the South

Eastern of Portugal railway, in the Alentejo from Vendas Novas to Beja and Evora, which he completed, with great labour and at little profit, to the satisfaction of the Portuguese Government; and he acquired so much the confidence of that mutable body, that the king appointed him a Knight Commander of the Portuguese military order of our Saviour Jesus Christ; and on his refusal to accept himself the contract for the construction of the extensions to Estremoz and the Algarve, proposed for that scheme of railway, his advice was solicited and taken with regard to the price and contract for those extensions. Whilst engaged on this work he was recommended, as an investment for his idle capital, to obtain the concession for a railway from Smyrna to Cassaba, in Asia Minor, which formed part of an extensive scheme of railways before conceded to other parties. Glowing reports of the lightness of the work and of the amount of local traffic induced him to invest a large fortune in this enterprise, just as the panic of 1866 reduced the price of ordinary railway shares to a minimum, and quite debarred him from disposing of any part of the profit and loss thereof. His capital not being sufficiently large to defray the cost of the entire work, he was compelled to borrow money at high interest in order to complete the railway, and although he ultimately succeeded in getting rid of all his liabilities, the efforts he made for that purpose, and the anxiety he experienced whilst the indebtedness remained, were so great as to undermine his strong constitution, which eventually gave way, and he died on 31st of March, 1871, of a complaint of the heart brought on by the constant anxiety under which he laboured. The Turkish Government was so pleased with the manner in which the works were carried out, that it was desired to confer on him the 2nd order of the Medjedi, which, however, certain circumstances prompted him to refuse.

Mr. Edward Price was noted by his employers not only for that inestimable and rare quality—good practical common sense—but also for his probity, his energy, and his thorough knowledge of work, which enabled them to rely on his carrying out any contract intrusted to him in the best practical manner, and on his completing it within the specified term. From the time he commenced work on his own account he never incurred any debts; and could always balance to such a nicety his liabilities with the means in his possession as to secure the profit due to ready money payments. His manners and speech partook of this character. He was never lavish of words either in talking or writing: his letters were concise and precise, and his address gentle and amiable.

Mr. ALFRED STANSFIELD RAKE was born on the 2nd of January, 1831, at Shaftesbury, Dorsetshire, and after receiving a liberal education at Birmingham, Thornbury, and Stoke Newington, commenced his professional career by entering the works of Messrs. Gilkes, Wilson, and Co., at Middlesbrough. Having a decided preference for iron ship-building, he, on leaving Middlesbrough, was for some time engaged with the firm of Messrs. Coutts and Parkinson, at Willington Quay, near Newcastle-on-Tyne, and subsequently entered into partnership as an iron ship-builder at Middlesbrough; but the business there proving less successful than was anticipated, the partnership was dissolved. Mr. Rake afterwards filled responsible appointments with Messrs. Dodds and Son, at Rotherham, with Messrs. R. Stephenson and Co., Newcastle, Messrs. Fairbairn and Co., Manchester, and then for two years with a firm in the west of Ireland. On leaving Ireland, he, in 1867, commenced business on his own account in Newcastle, as a consulting engineer and naval architect, and by his assiduity and perseverance, he soon established a large and lucrative connection, and achieved an amount of success beyond his anticipations. There is reason to think that unremitting attention to numerous professional engagements seriously undermined his health; and the anxiety conscientiously to discharge responsible duties caused him to neglect the earlier indications of failing strength, and eventually led to his premature decease just after completing his fortieth year. His frank and generous disposition endeared him to a large circle of relatives and friends by whom he was universally beloved, and he was as much respected by those with whom he was professionally connected, but who might not all have had the privilege of his friendship. Mr. Rake was elected an Associate of the Institution of Civil Engineers on the 3rd of February, 1863.

Mr. HENRY YARKER RICHARDSON was born at Appleby, Westmoreland, on the 7th of February, 1819. He was educated at the grammar-school of that town, and made some considerable progress both in classics and mathematics. In 1841 he entered the service of the late Mr. Robert Stephenson, and continued with his eminent firm in Newcastle-on-Tyne for eighteen years. Entering upon business on his own account, partly in Newcastle and afterwards in London, he had scope for the exercise of very great skill and energy in the several branches of commercial life in which he was engaged. Returning to Newcastle, he became the proprietor of a paper manufactory which flourished rapidly in his hands. He was cut off, in the midst of most active usefulness, by an instantaneous death on the 6th of December, 1870, in the dreadful railway collision at Brockley Whins, near Sunderland. He was a man of earnest piety, and very active in the duties of social and spiritual life. He has left a large family of ten children, who are orphaned altogether, as his wife's health rapidly sank after the accident, and she died in the following February. The railway authorities acknowledged the value of such a life by a very large sum in compensation; but a valuable life so suddenly closed has a price beyond estimation by mere pecuniary means. In mechanical knowledge he was, in a great measure, self taught; but he was possessed of a rare wisdom, and a practical ingenuity that gave promise of rapid advance in pursuits which he cordially loved. Mr. Richardson was elected an Associate of the Institution of Civil Engineers on the 14th of January, 1868.

MR. ROBERT RITCHIE, the second son of Charles and Mary Ritchie, was born in Edinburgh on the 25th of September, 1795, and his education was principally conducted at the High School of that city, He entered the Royal Navy as a midshipman in September, 1811, a post he speedily relinquished for the now extinct East India Company's naval service. After two voyages to India he left the sea, and joined in his father's business in Edinburgh, soon becoming the principal, devoting himself mainly to iron founding and kindred engineering manufactures, which, however, he ceased to pursue whilst still in early life. Mr. Ritchie was distinguished for his scientific and literary attainments, and he was a member of many societies. He was a Fellow, and, at one time, Vice-President of the Royal Scottish Society of Arts; a member of the Highland and Agricultural Society of Scotland; and was elected an Associate of the Institution of Civil Engineers on the 4th of February, 1845. For his literary communications he received seven medals from the two former societies, and once "special thanks." His writings have had a wide circulation, and are of a practical character. In his work on railways, published in 1846, he gave expression to his views on railway accidents. In 1842 and previously he advocated the application of steam to farming purposes, pointing out the many uses to which fixed engines might be applied. In 1851 he made a report, as secretary of the mechanical section for the Lothians, for the Great Exhibition of that year. But it was as an engineer in ventilating and warming, sciences in which he may be regarded as a pioneer in Scotland, that he was latterly chiefly engaged. His opinions on domestic, public, factory, ship, mining, farm steading, and forest ventilation, were published in various works between the years 1832 and 1862, and form a standard series on the subject; and the successful application of his views may be seen in Balmoral Castle, in Stewart's Hospital, the College Library, the Advocates' Library, and the Signet Library, the Register House, the General Post Office, and the Parliament House, and Courts of Law, Edinburgh, the Courts of Law and the General Post Office, Glasgow, in Marischal College, Aberdeen, and in numerous mansions, court houses, prisons, and churches scattered over the country. As a citizen of Edinburgh, so early as 1825, he occupied the position of Moderator of the Society of the High Constables, and in 1826 entered the Town Council. In 1829 he filled the office of Admiral of Leith, and more than once, commencing in 1827, was elected a magistrate of the city, doing the duty of police judge; and for several years he was Old Bailie. In 1854 he was Baron Bailie of Portsburgh; and, in 1855-56, was the last Baron Bailie of Canongate and Calton. As a governor of Heriot's Hospital he took a warm interest in that institution, and accomplished many improvements in connection with it; he also wrote interesting reports on the question—Who was the architect of Heriot's Hospital? He was for many years an active member of the Paving Board and of the Water Company, and of the Session of the Iron Church, and for several years sat as representative elder of the Town Council in the General Assembly of the Church of Scotland; recently he was Moderator of the High Constable and Guard of Honour of Holyrood, and besides holding other offices, was a member of the City Parochial Board. He was a moderate Conservative in politics, and took an active part throughout a long course of years in the committees and in canvassing for the Conservative cause in Edinburgh, and in 1837 was Chairman of the Edinburgh Conservative Association. Mr. Ritchie was a man of no ordinary ability. Honourable, straightforward, and manly, whilst not hesitating to expose any underhand proceedings, he did not shrink from expressing his opinions, and supported them with consistency and courage. His manner was retiring; he was a man of genial nature, and of much goodness of heart, and was recognised and valued for his sterling worth. For some time before his death his physical strength had been failing; and on the morning of the 1st of May, 1871, he was struck with paralysis, from which he never rallied, and expired on the 3rd of the same month in the seventy-sixth year of his age.

Mr. HENRY BEADON ROTTON, the youngest son of the late Mr. John Rotton, of Bath, was born in the year 1836, and was educated at Bruton Grammar School. He commenced his professional career under Mr. (now Sir D.) Gooch at the works of the Great Western Railway Company at Swindon, where he acquired a good practical knowledge of his profession. On completing his time, he was appointed to the situation of District Locomotive Superintendent of the Great Western Railway at Oxford, and while so employed he gave every satisfaction. In 1864, the Government of New Zealand requiring the services of an engineer and an assistant-engineer to erect a number of iron lighthouses on the coast of that colony, Mr. R. Aylmer, Assoc. Inst. C.E., received the former appointment, and Mr. Rotton was selected to accompany him as the assistant-engineer. To Mr. Rotton was entrusted the superintendence of the erection of the lighthouse on Maua Island, and of the lantern and light apparatus at Godley Head. These works were successfully carried out by him, the Maua Island one in particular requiring much energy and tact, but his ability was equal to the occasion, and the whole was finished and the lights exhibited in a comparatively short time. He returned to England in 1866, having fulfilled his engagement to the complete satisfaction of the New Zealand Government. He died in London on the 18th of June, 1871, at the age of 34½ years, deeply regretted by all who knew his warm-hearted, generous, and honourable disposition.

Colonel JAMES ROGER WESTERN, late of the Royal (Bengal) Engineers, the third son of Mr. James Western, solicitor, was born in London on the 28th of February, 1812. Entering the military college at Addiscombe, in the year 1827, he speedily became conspicuous for mathematical abilities, and passed first in mathematics in the following year, which secured his appointment to the corps of Bengal Engineers. On proceeding to Chatham, his talents and acquirements attracted the notice of Captain, afterwards Sir George, Everest, who was deputed to take the Indian Engineer cadets to the Royal Observatory, Greenwich, to indoctrinate them in practical astronomy, and in the use of the invariable pendulum for determining the figure of the earth. Captain Everest was shortly afterwards appointed Surveyor-General of India, and on the 15th of January, 1831, Western was attached to the great trigonometrical survey, as an assistant on his staff. In this capacity he took a prominent part in the measurement of the

Calcutta base line in 1831-2. In the Journal of the Asiatic Society for 1832, vol. i., page 71, there is a brief account of that operation by Mr. James Prinsep, with a sketch in which Western appears conspicuous at the 'boning' instrument directing the alignment. After the completion and verification of this base line, which was the first measurement made with General Colby's apparatus for the trigonometrical survey of India, he was deputed to conduct a meridional series of triangulation depending on the lofty mountain station of Parisnath, but was unable to continue it southwards of that place because of the disturbed state of the country. Unfortunately, ill-health, and a disagreement with his superiors about the manner of executing this work, caused him to leave a career so well suited to his tastes, after two years' employment on the survey. On the 22nd of September, 1834, he was ordered to join the head-quarters of the sappers at Delhi, and he proceeded as Assistant Field-engineer with the force under Brigadier-General Stevenson to Shekhawati, in Rajpootana, where the Military Engineer department was employed in destroying the Toorawutti forts, which formed the strongholds of the turbulent Rajpoot chieftains. In the cold weather of 1836-7 he surveyed a part of Ulwur, and reported his opinion upon a dispute between the native states Ulwur and Bhurtpoor, for the waters of a stream called the Rospirail, and the report was considered most creditable to his judgment. For the next four years he was engaged in draining the Nujjufgurh-jheel, near Delhi, and in other public works, having been appointed Executive Engineer of Delhi on the 9th of September, 1839, and of Berhampoor on the 28th of October, 1840. He returned to England in February, 1841, and with characteristic energy set to work to study civil engineering; but before his furlough had expired he was recalled to India on account of the Affghan war: in this, however, he took no part, but spent the next five years as Executive Engineer in Arracan, Rajpootana, Dacca, Tenasserim, and Dumdum. About the year 1843, questions arose as to the stability of the Bengal Military Fund. On this occasion he produced a most able and exhaustive report upon the subject. His ability as an actuary was at this time so well known, that he became the usual referee in all questions concerning shares in purchase of steps in regiments—no slight task, since a new schedule of quotas was required in every case. At the end of 1848 he was summoned to the second Sikh campaign, and took a prominent part in the siege of Mooltan; he was also present at the battle of Goojrat; and for these services was made a major by brevet on the 5th of June, 1849. That war having ended in the annexation of the Punjab, he became Executive Engineer of the Jullundur division, where his success in reducing building rates, and the saving effected by his arrangements, gave the highest satisfaction. Late in the year 1852 he obtained the command of the Bengal corps of sappers and miners, which he retained till he retired from the service, on the pension of a major, on the 23rd of January, 1855. From this time his business was the care of one daughter, left him from his brief period of married life, and the management of charities to which he contributed munificently, being Governor of Christ's and St. Thomas's Hospitals, an active member of the governing body of the Soldiers' Daughters' Home, and a regular subscriber to forty-four other charitable institutions. He was elected an Associate of the Institution on the 1st of March, 1842, and he died on the 13th of January, 1871, in the fifty-ninth year of his age, having shown himself in life, in the words of a brother officer, "a large-hearted, good Christian."

MR. CLEMENT WILKS was born at Peckham Rye, Surrey, on the 15th of February, 1819, and was the youngest son of the Rev. Mark Wilks, of Paris. He passed most of his early years in France and Switzerland, and took his degree of Bachelor of Arts at the Collège de Paris in the year 1836. After being engaged for a short time on the Paris and St. Germain railway, he came to England, and was articled to Sir Charles Fox, then of the London works, and Resident Engineer of the London and Birmingham railway. His professional education was continued in connection with Messrs. Fox, Henderson and Co. till 1841; and in the following year he had the chief management of a French engineering establishment on the Garonne, where he remained for three or four years. Returning to England, he entered into what proved but a short engagement with Mr. G. W. Buck, M. Inst. C.E., on the Ely and Huntingdon railway, then in course of construction. On Mr. Buck's decease he was associated with Mr. Hawkshaw in surveying for the Manchester and Southport line, and subsequently for the Lancashire and Yorkshire railway, in the neighbourhood of Heckmondwike. In 1850 he was engaged in superintending the construction of various public buildings in London, under the direction of the Society for Improving the Dwellings of the Poor, a model of one of which was erected in connection with the first Exhibition of 1851.

In the following year he left England for Australia, and immediately after arriving in Melbourne, was appointed Assistant

Colonial Engineer, a post he occupied for several years, being chiefly engaged in the construction of roads and bridges in various localities in that colony. In 1860 he visited the United States and Canada on private affairs; and returning to Australia resumed his former duties. The Victorian Government having inaugurated a scheme for supplying water to the various mining districts, he was invited to accept the post of Resident Engineer to the Water Supply, the duties of which he continued to discharge until his death, on the 2nd of May, 1871.

His professional ability, integrity, and zeal in the performance of arduous duties, often under circumstances peculiarly harassing, as well as his uniform courtesy, secured for him at all times the esteem and confidence of his superiors, whilst the kind consideration shown invariably towards those whom he employed won their warm regard.

During the last twelve months of his life he was much enfeebled by a lingering malady, and was yet found daily at his post, for his active temperament would not suffer him to seek the rest which might have prolonged his days.

Mr. Wilks was elected an Associate of the Institution on the 7th of December, 1869.

SUBJECTS FOR PAPERS.

Session 1871–72.

The Council of The Institution of Civil Engineers invite communications on the Subjects comprised in the following list, as well as upon others; such as—

- *a.* Authentic Details of the Progress of any Work in Civil Engineering, as far as absolutely executed (Smeaton's Account of the Edystone Lighthouse may be taken as an example).
- *b.* Descriptions of Engines and Machines of various kinds.
- *c.* Practical Essays on Subjects connected with Engineering, as, for instance, Metallurgy; or,
- *d.* Details and Results of Experiments or Observations connected with Engineering Science and Practice.

For approved Original Communications, the Council will be prepared to award the Premiums arising out of special Funds devoted for the purpose.

1. On the Application of Graphic Methods in the Solution of Engineering Problems.
2. An Experimental Inquiry into the Strains upon Arched Ribs, variously loaded, to ascertain the agreement between Calculation and Experiment.
3. On the Methods of Constructing the Foundations of some of the principal Bridges in Holland and in the United States.
4. On the Construction of Bridges of large span, considered with special reference to examples, now in progress or recently completed, in the United States.
5. On the most suitable Materials for, and the best mode of forming, the Surfaces of the Streets of large Towns.
6. On the Advantages and Disadvantages of Subways, for Gas and Water Mains, and for other similar purposes.
7. On the Theory and Practical Design of Retaining Walls.
8. On the comparative efficiency of different Steam and Hydraulic Cranes, and on the Application of Steam Power in the execution of Public Works.

9. On the Different Systems of Road Traction Engines, with details of the Results in each case.
10. On the Use of Concrete, or Béton, in large masses, for Harbour Works and for Monolithic Structures.
11. On Dredging Machinery, with details of the cost of raising and depositing the material.
12. On Excavating by Machinery, with a description of any Excavating Machines which have been brought into successful practical use.
13. On the various Appliances and Methods used in Rock-boring and Blasting, in this country and abroad, with details of the results obtained.
14. On Explosives, as applied to Industrial Purposes, particularly Nitro-glycerine, Dynamite, and 'Lithofracteur.'
15. On the Gauge of Railways.
16. On Economical Railway Construction and working.
17. On the Systems of Fixed Signals, and the connection between signals and points, at present in use on Railways.
18. On the details of construction of Modern Locomotive Engines, designed with a view to economy, durability, and facility of repair, with particulars of the duty performed, of the cost of repairs, &c.
19. On the best descriptions of Continuous Breaks, which have been extensively employed on Railways, and the general results of their working, both upon Inclined Planes and upon Levels; and on the use of cast iron, wood, and other materials for break-blocks.
20. On the best method of Utilizing the Resistance of the Piston, as a retarding break power on Railways.
21. On Street Railways, and the best mode of working them.
22. On the Water Supply of Towns, including a description of the sources of supply, of the different modes of collecting and filtering water, of the various incidental works, of the distribution to the consumers, and of the general practical results.
23. On the Theory and Practical Design of Pumps, and other Machines for raising Water; as well as of Turbines, and of Water Pressure Engines.
24. On the Employment of Steam Power in Agriculture.
25. On the Theory and Practice of the Modern Methods of Warming and Ventilating large Buildings.
26. On the Laws governing the Flow of Steam and other Gases in pipes, and on Experiments to determine these Laws.

27. On the best practical Use of Steam in Steam Engines, and the effects of the various modes of producing Condensation.
28. On the Results of the best modern practice in Marine Engineering, having regard particularly to Economy of Working Expenses, by Superheating, Surface Condensing, great Expansion, High Pressure, &c.
29. On Mechanical Appliances, worked by Steam, for use on board ship, as substitutes for manual labour, in loading and discharging cargo, in raising the anchor, in working the sails, &c.
30. On the Design and Construction of Gas Works, with a view to the Manufacture of Gas of high illuminating power, free from Sulphur compounds, especially Sulphide of Carbon; and on the most economical system of distribution of Gas, and the best modes of Illumination in Streets and Buildings.
31. On the Maintenance, by Sluicing, of the Harbours on the Coasts of France, Belgium, and Holland.
32. On the Sea Works at the mouth of the River Maas, and the effects produced thereby.
33. On the Construction of Tidal, or other Dams, in a constant, or variable depth of water; and on the use of cast and wrought iron in their construction.
34. On Steel, and its present position as regards production and application.
35. On the safe working strength of cast and malleable Iron and Steel, including the results of experiments on the Elastic Limit of long bars of Iron, on the rate of decay by rusting, on the effect of vibration or prolonged fatigue on the strength of railway axles, chains, shafts, &c., and on the relative extension and compression of wrought iron and steel under equal loads within the elastic limit.
36. On the Means in use for Sinking deep Shafts through quicksands, or other shifting material.
37. On the various Methods of Draining distant isolated sections of Mines.
38. On the best forms of Air-Compressing Machinery and of Hydraulic Engines for conveying Motive Power to deep Workings in Mines.
39. On the Theory and Practice of the Methods in use for the Artificial Ventilation of Coal and Metallic Mines.
40. On the Washing of Small Coal, and the Manufacture of Artificial Fuel.

41. On the Preparation and Utilization of Peat, and the Machinery connected therewith.
42. On the Systems and Apparatus at present used in Telegraphy.
43. On the Pneumatic Transmission of Heavy Trains through Tunnels, and of Light Weights through Pipes, with a Comparison between the Economy of the two Systems.

The Council will not consider themselves bound to award any Premium, should the communication not be of adequate merit; but they will award more than one Premium, should there be several deserving communications on the same subject. It is to be understood that, in awarding the Premiums, no distinction will be made between communications received from a Member or an Associate of the Institution, or from any other person, whether a Native, or a Foreigner.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, on the one side only, leaving a sufficient margin on the left side, in order that the sheets may be bound. A concise abstract must accompany every communication.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject. Enlarged Diagrams, to such a scale that they may be clearly visible when suspended on the walls of the Theatre of the Institution, at the time of reading the communication, should be sent for the illustration of any particular portions.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

The Communications must be forwarded, on or before the 31st of December, 1871, to the house of the Institution, No. 25, Great George Street, Westminster, S.W., where copies of this Paper, and any further information, may be obtained.

CHARLES MANBY, *Honorary Secretary.*
JAMES FORREST, *Secretary.*

THE INSTITUTION OF CIVIL ENGINEERS,
25, *Great George Street, Westminster, S.W.*,
1*st September*, 1871.

EXCERPT BYE-LAWS, SECTION XV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model presented to the Institution shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same, in any way and at any time they may think proper. But should the Council refuse, or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

NOTICE.

It has frequently occurred that, in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

[ORIGINAL COMMUNICATIONS.

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RECEIVED BETWEEN DECEMBER 1ST, 1870, AND NOVEMBER 30TH. 1871.

AUTHORS.

Adams, W. B. No. 1,284.—Train Resistance on Railways.

Andrews, C. No. 1,312.—The Somerset Dock at Malta.

Ansted, D. T. No. 1,286.—Relations of Geology to Engineering: Reservoirs and Embankments.

Armstrong, G. F. No. 1,295.—On an Extension of the Practical Application of Spectrum Analysis.

Beazeley, A. No. 1,296.—On Phonic Coast Fog Signals.

Bell, W. No. 1,307.—On the Stresses of Rigid Arches, Continuous Beams, and Curved Structures.

Blackburn, J. W. No. 1,300.—Engines in Underground Workings.

Grant, J. No. 1,305.—Further Experiments on the Strength of Portland Cement.

Imray, J. No. 1,306.—On the Construction and Conversion of Ordnance.

Jacob, A. No. 1,304.—The Treatment of Town Sewage.

Lefroy, H. M. No. 1,287.—A Steam-worked High-pressure Combustion Pneumatic Water-lifting Machine.

Moore, B. F. No. 1,298.—On the Transverse and Longitudinal Strains in Thick Hollow Cylinders.

Neville, P. No. 1,308.—On the Water Supply of the City of Dublin.

Rigg, A. No. 1,303.—Modern Heavy Artillery; chiefly in reference to Longitudinal Strength.

Sabine, R. No. 1,311.—On the Systems and Apparatus at present used in Telegraphy.

Samuelson, B., M.P. No. 1,299.—Description of two Blast Furnaces erected in 1870 at Newport, near Middlesbrough.

Siemens, C. No. 1,309.—Pneumatic Despatch Tubes: the Circuit System.

AUTHORS.

Thomson, D. No. 1,290.—Centrifugal Pumps.

Thornton, G. No. 1,285.—Notes on the Methods employed in putting down Screw Moorings in Lyttelton Harbour, Canterbury, New Zealand.

Towle, H. E. No. 1,291.—Account of the Basin, the Balance Dock, and the Marine Railways at the Austrian Naval Station of Pola, on the Adriatic.

Welsh, E. No. 1,310.—On the Pumping Machinery and Works at Lade Bank: River Witham Drainage.

Wilks, C. No. 1,288.—Description of the Outlet Tower for the Melbourne Waterworks.

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January 9, 1872.

T. HAWKSLEY, President,
in the Chair.

His Majesty Dom Pedro II. d'Alcantara, Emperor of Brazil, was unanimously elected, by acclamation, an Honorary Member.

The following Candidates were balloted for and duly elected:—Bradford Leslie, as a Member; Lieutenant Osbert Chadwick, R.E., William Drake-Brockman, John Fenwick, John Edwards Fraser, Alfred Edward Garwood, Alfred Kitt, Arthur Pye-Smith, Major William Swainson Suart, R.E., and Captain Charles Edmund Webber, R.E., as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. VIII., of the Bye-Laws, had transferred Peter Paterson, Leveson Francis Vernon-Harcourt, M.A., and Frederick Minshull Weedon, from the class of Associate to that of Member.

Also, that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—Arthur Lloyd Cochrane Bamber, William Boyd Fitzgerald, Richard Willett Hurst, B.A., John Hamilton Johnson, William Joshua Mason, George Henry Pole, William James Purvis, William Edwards Shaw, and Alexander Siemens.

Mr. Hawksley addressed the Meeting in the following terms, on taking the Chair for the first time, after his election as President:—

Gentlemen,

In accordance with the long-established usage of this Institution, I have now the privilege of addressing you from the Chair to which you have done me the honour to elect me. I purpose, therefore, to avail myself of this opportunity to place before you a condensed survey of the more prominent of the numerous results of Engineering skill by which the period of office of your distinguished and veteran ex-President has been rendered remarkable.

But before proceeding to the customary business of the evening, allow me to discharge with heartfelt satisfaction the most agreeable duty of congratulating the assembled Members of this Institution on the Providential restoration of His Royal Highness the Prince of Wales to a state of apparently assured recovery from that imminent danger by which, one short month ago, the life of His Royal Highness was hourly threatened. On no other occasion has the Nation manifested so unequivocally and so unanimously its entire sympathy with and for our beloved Queen, and with and for that estimable lady, the Consort of His Royal Highness. It will be a lasting satisfaction to us that by a solemn adjournment of our usual Meeting we recorded, in the only way open to us, our sorrowful appreciation of the magnitude and gravity of what then appeared to be an impending national calamity.

You will not need to be reminded that in this comparatively short interval we have seen a powerful nation, our friends and neighbours, all but crushed in one of the most fearful struggles the world has witnessed in ancient or modern times. I believe, indeed, that history records no similar instance in which, in the course of a few months, so many armies entered into conflict, so many sanguinary battles were fought, so many fortified places of great strength were reduced; and, finally, in which the capital of a nation of nearly 40,000,000 people became invested by 250,000 soldiers, and was at length compelled to capitulate, if not by the direct force of arms, at all events by the necessities which the exclusion of the supply of food enabled the victors to impose upon the vanquished. With the political situation of Europe immediately previous to the outbreak of hostilities, or with the altered, and still uncertain, political situation of the Continent as it now presents itself, however interesting and important the study of these conditions must be to all far-seeing and patriotic Englishmen, we in this Hall have no concern. Still, knowing as we do, and as the world at large knows too well, that the momentous events of which we—happily for ourselves—have been the passive spectators, were accomplished, not more by the peculiar military organization of one of the belligerents than by the superior manner and extent to which that belligerent had, by previous preparation and by sudden application, utilized the art and resources of the Engineer—it is impossible to conceal from ourselves that the disasters which have befallen our neighbours may, in turn, befall us, unless, indeed, we accept the warning, and prepare ourselves against them. I feel, therefore, under no restraint in expressing from this Chair the distinct opinion, and the warning it may be, that the future safety, and possibly, also, the national existence of this kingdom, will depend upon the judicious, wise and far-seeing policy with which the Government of the day, and of every day, shall be guided to the timely and effectual efforts to avail itself, for the purposes of national defence, of the devising and constructing ability of our experienced and practical profession. The recent conflicts in Russia, Denmark, Italy, America, Austria, and France have taught us that the wars of the nineteenth century have been equally remarkable for the suddenness with which they have been commenced, and for the rapidity with which they have been carried on to a termination most sad and disastrous to one, if not to both the contending parties; and we have learnt that, in the case of otherwise equally matched antagonists, the victory has been realized by the combatant that was the best provided with the weapons and munitions which, notwithstanding the existence of Government arsenals, had been devised in, and had been largely drawn from, the offices and workshops of the non-military engineer.

Nor can we exclude from our convictions that nations have latterly become relatively smaller exactly as the means of locomotion and the facilities for the exchange of ideas provided by the Engineer have become relatively greater, and that consequently there has for some time past existed a general tendency to the disappearance of the minor states by their absorption into the already major nationalities. A powerful neighbour will indeed always covet, and will generally find or invent an occasion for acquiring, the Naboth's vineyard of his own immediate locality, especially since the abandonment of the once accepted doctrine, that the maintenance of the balance of power was a common duty of friendly nations.

Now, discrediting as I do the popular notion that England is invincibly strong within, and that her "streak of silver sea" is sufficient for her effectual protection from without; and seeing, too, that her people are seriously dependent on other and distant countries for their daily supply of food, and equally so for their employment in the manufacture of exchangeable commodities, I venture to ask myself whether the engineering skill and resources of this country have been sufficiently availed of for the defence of our coasts and for the maintenance of our undoubtedly needful power at sea. Looking at the question from an entirely non-aggressive stand-point, and with the fullest desire to discountenance any wasteful expenditure of public money, I am nevertheless compelled to answer to myself in the negative; for although it may be admitted that we have of late accomplished something valuable by way of instalment for the defence of our hearths and homes, and that we are still prosecuting this good work in a hesitating and perfunctory manner, and that we may at some future day, if we be let alone long enough, bring the operation well-nigh to an end, yet I think you will all agree with me that the means of protecting our distant colonies, and of securing the safety of our world-wide commerce, without which commercial and manufacturing England is nothing, do not at this moment exist. We have, with the best intentions, expended much time and millions of money in creating a navy chiefly consisting of colossal and heavily-armoured ships, which (whatever may be their other and probably very valuable properties) are for the most part somewhat fair-weather sailers, which are in general incapable of carrying fuel for a prolonged voyage, and still less for a Nelsonian cruise, and which, by reason of their great draught, can enter but a small proportion of the number of the harbours of the world, or indeed of those of our own country.

The articles so much needed could, however, be well furnished by the combined efforts of our numerous engineers, ship-builders and machinists, in any quantity, but not, as many assume, at any moment, provided the opportunity were afforded by the prudent withdrawal of those official and, it may even be, Parliamentary impediments by which the way to the speedy attainment of so grand an object as the establishment of an effective oceanic police is now barred. These impediments are, undoubtedly, based on a preference for official designs and official manufacture, and, however well-intentioned, implicitly signify that the talent centred in a Government department is, in official estimation, more skilled and more capable than that which is to be found amongst the thousands of able men who have not been drawn within the magic circle of official life.

The numerous ships which have distinguished themselves by their speed, their seaworthiness, their capability of making and sustaining the strain of long voyages and of encountering the vicissitudes of weather and climate, not to say of occasionally undertaking warlike operations, are all the work of private builders; amongst such ships are the steamers which habitually run to the Mediterranean, to the East and West Indies, to New York, and even to Australia; and to these might be added the clever blockade runners and the wicked Alabama. Can our Navy boast of appropriately modified equivalents of these types?

Towards the proper construction of a Floating Policeman, I venture to suggest that the members of the Institution interested in this question should direct their attention to the best means of obtaining the following four essential properties (amongst others which will readily suggest themselves): First, a moderate draught; second, great stability; third, a high speed when under steam; and fourth, a competent stowage for fuel. These qualifications are not inconsistent; but a heavy-armouring would, I think, be incompatible and unsuited to the purposes to which such ships would in time of war be applied, namely, those of protecting our colonies, of convoying our merchantmen, and of scouring from the seas the ships of our enemies. For home service they would be equally useful, as it is obvious that few, if any, large armour-plated vessels could successfully withstand that attack of a cloud of rapidly moving sea hornets, each one armed with a single heavy gun.

With such a fleet, and the means which the genius of your Members of Council, Sir William Armstrong and Sir Joseph Whitworth, not to mention others, have placed at the nation's disposal, our citizens would feel safe and happy at home, whilst the nation would command that respect which continental governments and continental people never accord to the "barking dog that cannot bite."

For these reasons I should welcome the production, at the meetings of this Institution, of any practical Papers containing such information pertinent to this subject as will lead to an intelligent and temperate discussion of the most suitable forms and arrangements for ships of war, and for their steam machinery and propelling apparatus, and for the implements and munitions with which such ships ought to be provided and armed. In no way, as it appears to me, could this Institution at the present juncture serve its country better, or better promote, in the interests of peace, the advancement of practical science, and its application, if events should order, to the purposes of protective warfare.

Of the military constructions which have been erected in defence of the national arsenals, it is not my intention to speak further than to record with satisfaction the exceptional circumstance that your Past-President, Mr. Hawkshaw, was called in to assist the military authorities, and has devised, amongst other matters, a system of plating with wrought iron, so ponderous and so securely combined, that it is believed the heaviest shot fired from an enemy's ship will be unable to tell destructively upon any fort thus protected. It may however be remarked that most of our commercial seaports are, at least, as much exposed to an enemy's operations as are the arsenals, and that, unless these can be effectively protected by a fleet, it will become necessary to erect and maintain a considerable number of such superior land batteries as will keep the enemies' ships beyond bombarding range. The enormous expense of these immovable works, and the obvious objection that a seaport town presents a mark of great magnitude, and therefore a mark easy to hit, whilst a moving vessel, attacking from a distance of three miles or more, presents a mark small and exceedingly difficult to hit, render any project of this kind comparatively infeasible, if not altogether useless.

In making these observations I am, however, not unaware that many persons are impressed with the notion that in future war will be conducted on such chivalric principles that undefended forts and property will be generously spared by an enemy's forces. I do not concur in this view, nor do I conceive that, so long as it remains an object of war to cripple an enemy's means, and so reduce him to a speedy submission, it would be prudent for England to rely for the safety of its ports on the forbearing generosity of a vigorous and determined antagonist.

Turning now to more peaceful topics, I must first allude to the successful completion of one of the greatest, though not, perhaps, the most difficult, of the many important undertakings of the present age. The Alps have at length been pierced by the Mont Cenis Tunnel, and thus the south of France and the north of Italy have been placed in easy inter-communication by a line of railway which affords to England the most rapid means of transit to and from her Indian dominions. The conception of this noble work was distinguished by a grandeur which at one time seemed to imperil the realization of the scheme, and it is believed that if the Emperor Napoleon had not himself fully appreciated the importance and the practicability of the project when others doubted both, and thus brought the two Governments of France and Italy to the support of the undertaking, it would not have been proceeded with. The history of this laborious enterprise has so recently been before you, that it would be superfluous in me to attempt a particular description. Let it suffice then to refresh your memories by stating that the Tunnel was commenced on the 31st August, 1857, and that it was finished on the 14th September, 1871, thus occupying 14 years in its construction; that it is about 7½ miles long; that it is about 4,400 feet above the level of the sea, and about 5,100 feet below the summit of the mountain; that it was cut through strata, consisting for the most part of micaceous sandstone intermixed with micaceous schists, dolomitic, and crystalline limestones and limestone schists, and veins of quartz alternating with argillaceous schists, somewhat hard in their character, and occasionally decidedly difficult to penetrate, but fortunately yielding little water; that the excavations proceeded from both ends, and that the work was set out and directed with such extraordinary skill and accuracy that the junction was perfect in respect of both direction and level. The work was carried on by means of a very ingenious mechanical drilling machine, actuated by atmospheric air compressed by the Alpine water power in an ingenious apparatus placed at some distance without the mouth of the Tunnel, and thence conveyed to the drilling machine through iron pipes. The Tunnel was designed by and was constructed under the direction of the Italian Engineers MM. Sommeiller, Grandis, and Grattoni, of whom we may on this, the first occasion which has presented itself since the successful inauguration of this great international work, express a well-merited admiration, and to whom, although it be only by way of acclamation, the Members of this Institution may, I think, properly offer their warmest congratulations.

Another great work of foreign origin, the Suez Canal, has also been very recently so far completed as to enable large ships to pass through it from the Mediterranean to the Red Sea. The propriety of attempting this communication was at one time doubted, both on commercial and physical grounds, because whilst in the first instance it was believed, on the authority of a French survey, that the waters of the Red Sea were about 10 metres higher than those of the Mediterranean, and that therefore a current sufficient for the purposes of scour might be commanded, it was on a re-survey discovered that the two seas were practically on the same level, and that therefore no self-acting current of scouring power could be obtained. It was therefore feared the proposed channel must either become refilled by the drifting sands of the desert, or that it would need to be so continuously dredged as to involve a ruinous amount of working expense. For some time, namely, till the year 1860, the project languished, but at length, owing to the untiring exertions of Mons. (now Vicomte) Lesseps, and the encouragement afforded by the governments of France and Egypt, the undertaking was commenced, and after nearly ten years of indomitable perseverance, and the expenditure of many lives and much treasure, was so far completed as to enable the opening ceremony to be performed in the month of November, 1869, in the presence of His Highness the Khedive of Egypt, and of his imperial guests, the Empress of the French and the Emperor of Austria, and many distinguished persons.

The canal is 99 miles long, is, or is intended to be, 328 feet wide at the surface, and is, or is intended to be, 26 feet deep throughout. The work has been made, and the English and other commercial nations are freely availing themselves of the opportunities it affords as a water highway to the Red Sea, the Indian Ocean, the shores of the Pacific, and the continent of Australia. and are thus practically testifying to its present utility. Let us then hope that whether or not a commercial success is found to follow upon the realization of this great adventure, the means will be always forthcoming to prevent it lapsing into decay and desuetude.

Railway construction abroad has been greatly interfered with, and in some parts of Europe almost arrested by the recent wars. Whilst on the one hand international struggles have demonstrated the necessity of railways for the conveyance of food and munitions even to contending armies, yet on the other hand, the waste of funds and the paralyzing exhaustion caused by the reciprocally destructive efforts of the belligerents render for a time any important enterprise in the countries affected by the conflict all but impossible. Even adjacent countries are so far influenced by the interruption of the channels of business, and by the liability of becoming involved in the quarrel, that projects of public or private utility become neglected or cease to attract attention. Influenced by such events quite as much as by the financial collapse of 1866, we in England have, for some years, disregarded the various suggestions for improving the means of communication between this country and France, for extending the European system of railways to or towards our Eastern possessions, for uniting the Swiss and German railways with those of Italy, and for completing by private enterprise, rather than by governmental action, the vast ramification of iron roads which are required in India for the civilization, the good government, and the general advantage of 150,000,000 subjects of the British Crown.

On the last-mentioned of these matters I have to remark, with considerable anxiety, that our own Government has of late manifested a decided disposition to discourage private enterprise, which, with all its admitted defects, has made England the great nation she is. and to amass to itself all that most dangerous and necessarily ill-used if not misused power and influence which are created by the possession of many places, much patronage, and the distribution of large funds raised not for the few and comparatively uncomplicated purposes incidental to the care and protection of the people. but for the purpose of entering into an unnatural and depressing competition with the persons, sole or aggregate, from whose pockets the pecuniary means employed by the Government are derived. I am aware that in reply to, or in extenuation of this charge, it is attempted to be alleged that if there were no lenders there would be no borrower, and that, consequently, we who regard this action of the Government with distrust and apprehension have only ourselves to blame, since we have in our hands the easiest of all possible remedies, namely, that of withholding the funds. But is this really so? We are a money-making people, and we must have employment for our savings, even though when thus deprived of the opportunities of investing it in private enterprises we lend it to the Government: nevertheless we like, above all things, to invest our money in our own way, and to take a personal and individual interest in its employment, whether for fructification or the contrary. This is more or less the business of every business man, and it forms an integral and important part of the active life of the nation, and it has long been, and still is, a prominent and, when exercised with self-control and prudence, a most commendable cause of the intelligence, the energy, the progress, and the resourcefulness of the people. Deprive us of our enterprising spirit, reduce us to a grateful and dependent 3 or 4 per cent. receiving people, make the Government once for all paternal, and we shall speedily sink into the contemptible category of grown-up children, wishing and waiting in all possible affairs for the guidance and control of a central authority.

The existing railways of India are now both extensive and important, and at present possess the advantage of an uniform gauge of 5½ feet. This audience will therefore be surprised to learn that this existing uniform gauge is now to be departed from, and that upon the obviously crotchetty suggestion of some unknown individual the French metre gauge of 3 feet 3⅜ inches is in future to be employed.

In India, then, is about to be introduced the very evil consequent upon the absence of uniformity of gauge from which the wise and deliberate action of an experienced private enterprise in England is now busied in effecting our emancipation; and also to be initiated, for no useful purpose that I can perceive, one of the worst founded and most perplexing measures of length with which it has been my fortune to become acquainted. A measure which bases its claim to universal acceptance on the intangible ground that its length is, by its own unprovable assertion, exactly one ten millionth part of a quadrant of the earth's equatorial circumference! The introduction of the French metrical standard into India might indeed be possibly justified on the ground of expediency if England had previously adopted it, but till then I shall venture the assertion that to attempt to force upon the Oriental mind a novel system, and the labour of acquiring what will be to it an uncouth jargon, is as injudicious as it will certainly be unsuccessful. Nor can I conceive on what sufficient grounds it is being attempted to introduce the measures of France into use in this kingdom. The English unit of length, the yard, is just as capable of being referred to a natural standard as is the French unit, the metre; whilst the English unit, either as the yard or the foot, has been adopted and is used by far more millions of people than are now using the French unit. In Russia, in the United States, in Canada, in the East and West Indies, in Australia, and throughout the British Colonies in which the English language is spoken, the established English measure of length is exclusively employed, and these are the countries in which fully four-fifths of the commercial business of the world is carried on. Nor does the "ten finger" system of decimals, frequently employed as an argument in favour of the introduction of the metre, confer any advantages which are not more than counterbalanced by its disadvantages.

In the British Islands, many engineering works of importance have been unostentatiously brought to a successful completion during the past two years. With respect to some of these you are already well informed, and with respect to others you will, I hope, shortly become so through such communications to this Institution as the able designers of those works may be induced to present. I therefore now pass without further remark to the branch of Engineering, in the practice of which I am myself the most interested, and upon which I can therefore address you with such confidence as a long and varied experience may justify.

This branch of Engineering embraces, and for the most part restricts itself to, the practical application of those of the physical sciences which relate to the properties, conduct, and treatment of fluids, whether inelastic or gaseous. It therefore comprehends within its scope the provision and distribution of water and gas for the supply of towns; the collection, conveyance, and utilization of sewage; the employment of atmospheric air as a means of impulsion in tubes, and for the ventilation of mines; the improvement of rivers and estuaries; the reclamation and defence of land from the sea; the drainage of fens, and the collection and application of water for use in irrigation; and it even renders *its* assistance to the determination of the suitable form, and the amount of mechanical power, to be given to a ship to enable it to fulfil the conditions imposed by the requirements of commerce and the necessities of war.

From this very partial enumeration of the professional occupations of the Hydraulic Engineer, it may be inferred that this department of our practice is replete with scientific and practical topics of no common interest. Accordingly, to the discussion of these and their allied subjects this Institution has ever been willing to afford its best and most effective assistance, and, speaking on my own behalf, I can truly state that, from these discussions, I have not only derived many advantages in the solution of practical difficulties, but that I have also experienced the further benefit of having my mind driven from habitual lines of thought into new tracks, which have not unfrequently conducted to improved results.

If the last few years have contributed little to our former fund of purely scientific knowledge, the works they have seen executed have not only been both numerous and important, but are such as have added greatly to the not less necessary stock of practical data which, when generalized by means of comparative diagrams, or other well-known methods of treatment, become the foundation of the valuable empirical rules or formulæ by which every careful Engineer is guided in the numerous cases which lie without the confines of scientific investigation. In this way, for instance, we have become acquainted, within narrow and gradually diminishing limits of error, with the extent and effects of the periodical fluctuations of observed rainfalls, and with the influence of elevation and position on the amount of water capable of being utilized for the supply of cities; and with the allowances to be made for the losses of evaporation from differing surfaces of land and water. In like manner, we can now estimate with considerable precision the magnitude of the floods for which provision must be made in the construction of weirs and bye-washes. We have gradually attained to rules of construction more satisfactory than the 'rule of thumb' and 'scowl of brow' methods to which our ablest predecessors were compelled to resort whenever they were brought face to face with a novel constructional problem; and, finally, we have become acquainted with the true measures of the wants and requirements of the very variously employed populations of our widely differing towns, and even with the limits within which waste may be controlled without the imposition of any restriction on the use of water, by the adoption of simple and judicious regulations applicable to the construction and arrangement of the consumer's domestic fittings. The data thus derived are too numerous, and would require too large an amount of explanation, to justify me in placing them before you on this occasion. They shall, nevertheless, be communicated in another form. The information lastly referred to has, however, a special interest attaching to it, not only because the system of constant supply is being rapidly introduced into provincial towns, but because Parliament, in the last Session, passed a measure for the almost immediate application of it to this metropolis. This Act comes into operation on the 21st of the ensuing month, when the Metropolitan Authorities will become entitled, in the language of the Act, to be "of opinion that there should be in any district a constant supply." The fittings in use in this metropolis are, however, of a kind and are in a condition so thoroughly unsuited for the reception of the constant supply that the greatest care and caution must be exercised in its introduction, on the one hand to prevent an unsustainable amount of waste, and, on the other hand, to avoid the destruction of property which will otherwise result from the bursting of pipes and the overflowing of cisterns. Not only are the consumer's pipes and fittings commonly of a very unsubstantial character, but in too many cases they are built into walls, and are carried behind plastering, and are laid within ceilings to which no means of access are afforded; and, as a rule, the water-closet apparatus, however ornamentally it may be cased, is, to say the least, in a very imperfect and unsatisfactory state, as are also all the over-flows and air-pipes, which for the most part communicate with the drains, and so operate to introduce the noxious sewer gases into the apartments in which the apparatus is placed. A provision is indeed usually made (which, however, not unfrequently fails) to prevent this mischievous consequence by trapping the air and over-flow pipes with water afforded by the periodical overflowing of the cisterns, but as this existing system of intermittent waste would become continuous and ruinous if the water were constantly supplied, it follows that along with the alterations due to the introduction of the constant supply other structural alterations, in many cases of a still more extensive character, will need to be effected.

The success or failure of this well-intended measure will depend then not so much upon the Water Companies as upon the discretion with which the public authorities may proceed to bring it into operation. If the authorities act with due caution in the selection of small districts, and by preference those in which the dwellings of the industrial classes most abound, and then, after reforming the fittings of the one district, advance to a second, and so proceed from time to time, a successful issue may be anticipated; but, if the authorities allow themselves to be actuated by injudicious and impetuous representations, a sudden revulsion of feeling and a consequent failure of the Act will become inevitable.

Amongst the questions involved in the discussions relating to the measures proper to be adopted for supplying towns with water, is that of the selection of the fitting source; and of late years some theoretical chemists have gone so far as to assert that the presence of nitrates, nitrogen, organic carbon, and common salt in potable waters, are infallible indications of the presence of matters injurious to health and not improbably dangerous to life itself. Nay, even the unwarranted phrases, "previous sewage contamination," and "solid impurity," have been invented to frighten her Majesty's subjects from the use of some of the purest and most harmless, as they are certainly the most agreeable descriptions of waters the world can furnish. Again, on the occasion of an epidemic alighting on any of our English cities, an official medical man is now usually sent from a Government Department, and in the majority of instances, forthwith charges the temporary prevalence of disease upon the character of the water supply, I trust to be able, in a very few words, to dispel these, and, with them, all similar delusive notions. In the first place, I find as a statistical fact, that the towns in which the highest death rates have occurred are precisely those towns in which the commended waters are supplied. In the second place, I find, as another statistical fact, that in the towns in which the lowest death rates have prevailed the discommended waters are habitually drunk. In the third place, I find, as a further statistical fact, that in the cases in which the character of the water supply is unvarying, as, for instance, where the water is derived from deep shafts sunk in the open country, and in situations quite remote from population, the death rates of the towns thus supplied exhibit, when plotted on a diagram, precisely the same undulations and transitions from the minimum to the maximum, and again from the maximum to the minimum, that are exhibited in the instances of those towns in which the supply is, and must necessarily be, subject to extreme variations in the very particulars upon which the theorists base these truly alarming doctrines. In the fourth place, I find, as a fact in chemistry, that the noxious compounds for the presence of which the water supply and the water suppliers are endeavoured to be made responsible are actually furnished by rain or the atmosphere, and sometimes by both, or that they are actually existing, more or less abundantly, as ordinary mineral constituents of the strata from which the water is withdrawn. Whilst, however, I am thus led by a diligent investigation of comparable results to the irresistible conclusion that the doctrines in question rest on no solid foundation of ascertained fact or inductive theory, I do not on that account rush to the opposite extreme, and declare my opinion to be, that the Hydraulic Engineer may properly ignore the chemical inquiry, and in general accept any source from which a merely competent supply can be obtained. On the contrary, as it seems to me, it is the first duty of the Engineer to investigate the quality of the water obtainable from every available source, and to recommend that one which, under the special conditions of the case, would, on the whole, be the most suitable for the general purposes of the population. Thus for the supply of a manufacturing town in which water is to be largely used for business purposes a soft water collected from moors, although it may not be colourless, will prove to be the most advantageous; whilst for the supply of a non-manufacturing town, a coloured water, whatever might be its other useful properties, would not be tolerated. In the manufacturing districts of Yorkshire, the brilliant water with which Brighton is satisfactorily supplied would be contemned on account of its hardness, whilst, in Brighton, the softer waters with which many districts of Yorkshire are also satisfactorily supplied would be repudiated on account of their peaty colour.

On the subject of the removal of the sewage of towns, no new suggestions of importance to the professional Engineer have recently appeared, nor, indeed, does it seem that in this department of municipal improvement much remains to be accomplished. It is, however, worthy of remark, that in house construction it seems desirable to abandon the use of earthenware tubes with numerous and imperfect joints, and to substitute the use of iron pipes, with few and perfect joints, care being taken to provide a sufficient number of flanched or tightly-stoppered branches, to afford the means of access to the interior. By this simple arrangement, the escape of foul water and fœtid gases from the drains into the lower stories of our dwellings may be effectually prevented, and it will become a comparatively easy matter to apply in connection with such pipes an effective apparatus without the house for preventing the access of contaminated air from the main sewers. In many cases, the so-called 'ventilation' of the sewers is much neglected, and invariably with the natural result that the pent-up sewage gases make their escape at the place of greatest pressure or least resistance, and commonly into some house towards which the sewer ascends.

The question of the best means for effecting the purification of sewage water, and for the utilization of sewage matter, is still unsettled, and the controversy has assumed the dimensions and character of a party conflict in which the fact that the truth is not wholly with either party, and yet is partly with each, has been almost if not entirely lost sight of. That the application of liquid sewage in aid of the cultivation of land may be the means of raising prodigious crops of certain descriptions of vegetation, no one will deny; but it is far from being established that the results can be realized with profit, or indeed without occasioning a serious loss, when the operation is to be performed, not at the cultivators' will, but under the constant pressure of legal and sanitary obligations. Nor has it been shown how or where the larger towns can acquire, at a reasonable distance, of a suitable quality, and at the requisite elevation, the enormous areas of land the employment of this system requires, or how or where a daily market is to be found for the excessive quantities of the peculiar and perishable productions of an extensive irrigation farm. I admit the principle is sometimes applicable to the needs of small communities, but I have not as yet seen any evidence of its general availability in the cases of large communities; although, of course, special instances, exceptional to any general rule, may perhaps exist.

On the other hand, the process of purification by chemical means seems to me peculiarly suitable for adoption in those frequent cases in which the utilization of the sewage by the process of irrigation is infeasible. That the sewage can be readily cleansed by chemical means to a sufficient extent to render the effluent water reasonably admissible into a running stream I have often witnessed. That the process has hitherto been conducted with all the care and attention it requires I do not believe, and that it is, or can be made, a source of profit to the manufacturer of artificial manures remains to be demonstrated. As an Engineer wedded to no system, and belonging to no party, I desire that this process should be allowed that measure of fair play which has not hitherto been accorded to it, if only for the not unimportant reason that it involves a capital of about an eighth or a tenth part of that which must be embarked in works of utilization by irrigation, and I also wish that it should not be hastily ignored and discountenanced by or in consequence of central interferences with the discretion of local authorities.

In the manufacture and distribution of gas for the purposes of illumination no improvements of much importance have been recently effected, nor does it appear to me probable, that so long as we command an abundant supply of coal, the use of gas produced from that article will be superseded, or that the methods of distillation by heat and distribution through pipes, now in use, are likely to undergo much alteration. It is, however, of interest to Engineers to know that, year by year, gas undertakings are increasing both in number and magnitude, and that the consumption of gas in nearly all our large manufacturing towns has become duplicated in about every eight years, from 1840 to the present time, and that between thirty and forty millions of private capital are now invested in the gasworks of these kingdoms.

Atmospheric air as a motive agent will, I think, make its way into more frequent employment. For several past years its value, as a means of propulsion, has been little, if at all, recognised; probably in consequence of the universal failure of the atmospheric railways established in England, Ireland, and France; and hence the study of the circumstances under which this fluid may be rendered serviceable has been almost entirely abandoned by the members of our profession. Latterly, however, the success which has marked the application of this system by Mr. Siemens, to facilitate the delivery of postal telegrams, both in Berlin and London, has again attracted the thoughts of Engineers to this subject. The peculiar properties of elastic media, and the ease and safety with which atmospheric air, as one of such media, may be employed for the transmission of the lighter descriptions of goods, and even exceptionally for the conveyance of passengers, especially at moderate speeds, and for short distances, and in situations where other ordinary means would be inconvenient or out of place, commend the system to our unprejudiced consideration. But it may, nevertheless, be noted, that the very nature of fluid friction, which increases directly as the square of the velocity and as the length of the column to be set in motion, precludes the possibility of this system being advantageously compared on merely economical grounds with other mechanical methods of effecting equivalent objects. On the score of convenience alone this system must rest its claims to support, but the sacrifices of power we are in the constant habit of making, in order to attain our ends by any methods more convenient than others, justify me in assuming that merely economical objections will not prevent the adoption of this system for those purposes of convenience for which it is more peculiarly suited.

For the improvement of rivers and estuaries, no newly designed works have, I think, been carried into execution in this country during the past two years. Steady progress has, however, been made with those which had been previously undertaken. I point in particular, and with peculiar satisfaction, to the truly magnificent walls and terraces recently erected by the Metropolitan Board of Works for the embankment of the River Thames; and I trust the time is not far distant when both sides of the river will undergo the like treatment from at least Southwark Bridge to Battersea. This end accomplished, the metropolis of England will present from its bridges a perspective of unrivalled beauty.

In works of reclamation, nothing of importance has been undertaken, possibly because of the now almost settled conviction that to wage a great war with the mighty deep is, in truth, only a mode of performing the very unprofitable operation of casting useful money into the sea. In this conviction I entirely concur, but I nevertheless know that valuable accretions may frequently be made to sea frontages, at little cost, providing the operation be limited to a depth of three or four feet, and that it can be naturally assisted by the deposition of an argillaceous, or other adhesive and compacting warp.

With regard to the collection and application of water (other than sewage water) for the farmers' use in irrigation, little has been or indeed can be effected in this country; because, firstly, running streams are common property, and as such are very properly protected by law for the common use. Because, secondly, the English climate is neither sufficiently hot nor sufficiently arid to render irrigation necessary, or, indeed, useful for the purposes to which it is freely applied in warmer and less humid countries; and because, thirdly, the very undulating character of the surface of England renders the laying out of the ground too costly for the purses of either landlords or tenants. Add to this that irrigation must in England be almost universally assisted by a carefully-devised and expensive system of under-drainage, and we see at a glance the why and the wherefore it is that the British farmer appears to the agricultural theorist so "unaccountably indifferent" to the advantages alleged to be offered by operations of this description.

With regard to the last and not the least important of the topics on my list, viz., the determination of the forms and appliances of ships, I am happy to acquaint you that the Government has, on the nation's behalf, authorized a Committee, consisting of Lord Dufferin (Chairman), Admiral G. Elliot, Rear-Admiral A. P. Ryder, Rear-Admiral G. T. P. Hornby, Rear-Admiral W. H. Stewart, C.B., Captain J. Goodenough, Captain A. Hood, C.B., A.D.C., Sir W. Thompson, Mr. W. Froude, Professor Rankine, Rev. Dr. Woolley, Mr. G. W. Rendel, Mr. P. Denny, Mr. T. Lloyd. C.B., Mr. G. P. Bidder, and Lieut.-Colonel Pasley (Secretary), to make an exhaustive scientific and experimental investigation of the laws of the stability and frictional resistance of floating bodies. From the results of this investigation, and the recognised ability of the gentlemen by whom it is being conducted, I anticipate discoveries of a very interesting and a more than usually practical character—discoveries useful alike to the Engineer, the ship-builder, the Admiralty, and the merchant. When the report of the Committee becomes available to the profession, it will, I trust, be freely and vigorously discussed within the compass of these walls, to the end not only that we, as Engineers, may the better comprehend its import, but that we may also have the opportunity of exchanging our individual views and ideas and experiences upon, and respecting, the several matters to which that document will relate.

On the subject of professional education I wish to say a few words, and I would address them rather to each one of the 2[illegible] Students of this Institution who may happen to be now present than to the Members who have acquired and who have usefully employed that peculiar knowledge by which they are severally known and distinguished.

To the Students, then, I would say:—1st. Of all things, don't attempt too much. 2nd. Keep up and augment your knowledge of mathematics and the applied sciences, especially of those sciences which are most needed in that walk of the profession which you have selected for your own path; but again, I say, do not attempt too high a flight, for if you do you will never become a practical man. 3rd. Do not let your French grow rusty, and acquire German, if your leisure and aptitude are sufficient for the purpose, because your future avocations may be in countries in which these languages are either habitually spoken or are in considerable use. 4th. Acquire in the office, and by the study of esteemed works, a knowledge of form and design. 5th. But bearing in mind that you will never become a practical Engineer on theory alone, take every opportunity which presents itself of becoming apt in surveying and levelling, and in the methods employed in the setting out of works; learn the uses and applications of tools; make yourselves able to distinguish a good material from a bad material, good workmanship from bad workmanship, sound ground from treacherous ground, good puddle from bad puddle, good mortar from bad mortar, and a good workman from a bad workman. This knowledge is not to be obtained in a school, a college, or an office, and cannot be learnt from books. 6th. Make yourselves acquainted with every description of plant, and all the appliances and contrivances which an experienced contractor employs for the purpose of rendering a paper design into a substantial construction. 7th. Keep brief treatises on geology and chemistry always at hand, for some acquaintance with these sciences cognate to Engineering is, in the present day, almost essential. 8th. Practise as much as possible the art of mental computation, for this will give you the means of almost intuitively arriving at determinations on questions of cost, and of at once seizing on the best of several alternative plans or methods. 9th. Be not afraid of soiling your hands or dirtying your boots, but be in every other respect—in thought, feeling, and conduct—a gentleman.

I shall, on my part, be happy to afford to the Students of the Institution all the opportunities in my power; and therefore if they will do me the pleasure to accept an invitation to visit, with me, the Leicester Waterworks, one of the most recent constructions of the kind, and almost the only one which combines in itself the storing, the gravitation, and the pumping systems, I shall be only too glad to make all the necessary arrangements for this purpose.

In conclusion, I must again acknowledge the honour you have conferred upon me; and this the more especially that I cannot do other than feel that to become elected to the Chair of this Institution is to have attained the highest position to which a British Engineer can aspire. I will endeavour to perform the functions of the office as effectually, and, I trust, as worthily as in me lies. That I may count on your cordial support for the maintenance of order in your debates, and in the discharge of my other official duties, I feel fully assured.

Being duly moved and seconded, it was

Resolved,—That the President be requested to permit his Address to be printed and circulated with the Minutes of Proceedings.

January 16, 1872.

T. HAWKSLEY, President,
in the Chair.

The Discussion upon the Paper, No. 1,307, "On the Stresses of Rigid Arches, &c.," by Mr. W. Bell, was continued throughout the evening.

January 23, 1872.

T. HAWKSLEY, President,
in the Chair.

No. 1,312.—"The Somerset Dock at Malta." By CHARLES ANDREWS, M. Inst. C.E.

THE Royal Dockyard at Malta occupies, and gives its name to, one of four inlets or creeks, which extend nearly at right angles to the Grand Harbour on its south-east side, opposite to the city of Valletta. The original Dockyard belonged to the Knights of St. John, and was commenced under the administration of the Grand Master Emanuel Pinto in 1765, and was continued nearly to completion by the Grand Master Emanuel de Rohan; but its suspension became inevitable in 1789, when the French National Assembly seized upon the most valuable sources of their revenue, and thus prepared the Order for its final destruction in 1798. The fleet of the knights contained many vessels of considerable size. In the squadron despatched by them against the Bey of Tunis in 1770 the largest vessel contained nine hundred men: it was propelled by banks of rowers, under the command of thirty knights. Extensive buildings were erected upon the shores of the Dockyard Creek (then known as the "Harbour of the Galleys"), beneath which the galleys were drawn up in times of peace; and several now remaining are still serviceable, for the purpose of building and repairing the boats of Her Majesty's fleet.

The possession of Malta was secured to the British in 1814, and steps were then taken to improve the Dockyard. A small Graving Dock was commenced on the east side of Dockyard Creek, near St. Margharita Hill; but from difficulties caused by the broken character of the rock, and consequent leakage of sea-water, it was never completed, and was subsequently converted into a boat-slip.

The next attempt was made in 1841, when what is now known as the "Old Dock," or "Dock No. 1," was constructed at the head of Dockyard Creek. The foundation stone was laid by the Governor, Sir Patrick Stuart, June 28th, 1844, and the dock was opened on the 5th September, 1848, when, for the first time, a

British vessel of war was refitted for sea service in Malta. The designs for this Dock were furnished by the late Mr. W. Scamp, M. Inst. C.E., who likewise superintended for a considerable time its construction. The following are its dimensions, viz.:—

Length over all	310 feet.
Ditto on the floor	230 „
Width between the copings	82 „
Depth on the cill	23 „
Ditto on the floor	25 „

The cost of this work was about £60,000.

In 1856 this dock was lengthened 294 feet at the head, thus making the total length on the floor 524 feet, and the cill was lowered 2 feet. A sliding caisson was put in at a point 270 feet from the old one, so as to form two separate docks if required. The additional portion was 90 feet in width between the copings, and 25 feet in depth on the blocks, the floor being 2 feet lower than the old dock. Its cost was about £90,000, and it was opened in 1862.

In the meantime, the requirements of an iron-clad fleet made it imperative that a still larger dock should be constructed; but a great difficulty was found in providing a site near the present Dockyard. The Admiralty were ultimately led to negotiate with the Local Government for the possession of the adjoining creek, formerly called the "Harbour of the French," and now the French Creek. This valuable locality, from its perfectly-sheltered position, was at that time fully occupied by the Maltese commercial shipping, and upon its shores a large business was carried on in building and repairing vessels. In order to provide a suitable place for the transfer of this trade, it was decided that the head of the Grand Harbour should be increased by about 88 acres, with ample wharves, &c.; and an agreement was concluded between the Admiralty and Sir Gaspard le Marchant (on behalf of the Malta government), in May, 1859, for this purpose. These works, upon which a sum of about £250,000 has been expended, under the supervision of the Author, are now in the occupation of the commercial shipping. They are of considerable magnitude, and would require a separate Paper for their description. The original design was prepared by Mr. Scamp, but this was considerably modified and enlarged by Lieut.-Colonel Clarke, R.E., C.B., Assoc. Inst. C.E., the Director of Works to the Admiralty.

As a means of providing earlier accommodation for the fleet, pending the completion of the harbour works, a graving dock was commenced in 1862, in the new harbour extension, at a point where the solid appearance of the rock promised great economy and rapidity of construction, and which it was proposed to appropriate subsequently to commercial purposes. At a very early stage, however, a strong local opposition was encountered, and several other sites were pointed out as possessing greater advantages. Such differences of opinion between the chief Officers of the Navy, the Maltese Government, and the commercial classes, were calculated to lead to much loss of time, and the result was a personal investigation on the spot by their lordships, in order to decide the question.

In September, 1864, the First Lord of the Admiralty, his Grace the Duke of Somerset, visited the island, accompanied by Sir Spencer Robinson, Admiral Drummond, and Mr. H. C. E. Childers, M.P. The several sites were carefully examined by Lieut.-Colonel Clarke, a short time previous to the arrival of their lordships, and that officer advised the abandonment of the dock in the harbour extension, and selected another site in the French Creek, which, while offering the great convenience of proximity to the dockyard establishments, admitted of immediate commencement, with but little inconvenience to the shipping of that creek. The report of Colonel Clarke was at once adopted by their lordships as meeting the views of all parties; and the works were commenced in 1865 from his designs, under the direct superintendence of the Author.

The general plan and sections of the dock are shown on Plate 4. The length on the floor is 428 feet, and at the coping line 468 feet; the width of the floor is 42 feet 6 inches; the width between the copings is 104 feet; the width of the invert is 80 feet, and of the entrance 83 feet; the length of the entrance, from the caisson in the centre, is 256 feet; the depth of the invert, floor, and entrance below the average sea level, is 33 feet 6 inches. The floor rises 12 inches from the invert to the head for drainage, and is rounded 1½ inch transversely, for the same purpose. The floor by this arrangement is always kept well drained in the centre, where the workmen have the least working space. The timber slides and side steps are 5 feet wide. The work was partly executed by contract (several Maltese local contractors and builders being employed) and partly by day work under the direction of the Author.

The dock, inclusive of the caisson, cost about £120,000; the entrance cost £30,000 (exclusive of clearing the rock from the site), and the dock was opened on the 16th February, 1871, by Vice-

Admiral Sir Hastings R. Yelverton, K.C.B., the Commander-in-Chief; in the presence of His Excellency, General Sir Patrick Grant, G.C.B., G.C.M.G.; H.M.S. 'Caledonia' being the first vessel admitted.

PRELIMINARY WORKS, EXCAVATION, ETC.

The site alluded to was occupied by an old fortification, called the Demi-Bastion St. Raphael, and lies immediately beneath the Bastion and Cavalier of St. Michael, the point upon which the main assault of the Turks was directed during the memorable siege of 1565, relics of that event being subsequently met with in the excavations. It formed a plateau about 55 feet above the sea level, bounded on the margin of the creek by a bastion wall 72 feet high, and on the side adjoining the Dockyard by an elevated road leading to the neighbouring town of Isola. As there was no communication between the two sides of this road, the first operation was to tunnel under it from the Dockyard about 8 feet above the wharf level, through solid rock, for the purpose of conveying the excavated material to barges in the Dockyard Creek for removal to sea. As this tunnel was 80 feet in length, 18 feet in width, and 11 feet in height, it was not completed, ready for use, with tipping stages and wagon roads, before the end of September, 1865. In the meantime a convenient tract of ground was found on the Corradino Hill, about 60 chains distant; and in June of that year the excavation was commenced at the head of the dock, upwards of one hundred carts and mules being shortly employed at this point.

In order still further to expedite the preliminary operation of clearing the site to the wharf level, a second tunnel was commenced in September, extending from the Dockyard to the head of the dock; its dimensions were, length 230 feet, width 11 feet, and height 12 feet. It was cut in the solid rock throughout, and was ready for use, with the necessary loading shoots and wagon roads, by the end of December. Permission was also obtained from the local government to erect a similar loading stage for barges in the French Creek. This was completed by the end of December, so that by the beginning of 1866 access at all points was fully obtained for excavating purposes, at which period about 250 cubic yards of rock, &c., were daily removed.

A convenient arrangement for continuing the removal of rubbish during certain times, when the barges were unable to proceed out to sea, was thus made. At such times, the wagons, instead of being tipped over the shoots, were discharged through apertures between the rails at the end of the tunnels, where vacant spaces were available for the purpose, under the temporary staging; such spaces being subsequently emptied with baskets or barrows, at a very small additional expense. At the first tunnel 800 cubic yards could be thus temporarily stacked, and at the second tunnel 900 cubic yards.

By July, 1866, the site was thus sufficiently cleared to the wharf level, 6 feet above the sea, to permit of the excavation of the dock pit below that level being proceeded with; and a trial shaft was sunk, at a point about 100 yards from the caisson groove, to a depth of 50 feet, in the centre line of the dock, to ascertain the water-bearing character of the rock. The result was very encouraging, as no fissures were met with, and the water arising from slight cracks and partings only amounted to about 4 gallons per minute. A channel, 6 feet wide, was then cut from the shaft towards the entrance, in which several fissures were exposed, but very little water was discharged from them. Expectations of considerable economy in pumping were much strengthened, and an 8 H.P. portable engine, with one of Gwynne's centrifugal pumps, was put into use on the 11th August, and a 10 H.P. engine, and another pump of a similar kind, on the 3rd October, to relieve it when under repair.

A large pump-well, for temporary use, was formed in the centre line of the dock, 40 feet outside the caisson groove, for receiving two 20-inch barrel pumps, to be worked by a fixed 35 H.P. marine side-lever engine, formerly in H.M. ship 'Wilberforce;' and these arrangements were considered ample, as at that time the total leakage from the sea was only 300 gallons per minute, which was easily kept down, to a depth of 25 feet below the sea, by one of the small portable engines.

In the sinking of the temporary pump-well, a fissure was met with, 6 feet below the sea, discharging 30 gallons per minute, which increased slightly at a further depth of 17 feet, where a cavity was found, about 20 feet long, filled with black mud. This was a fact of some interest, in a geological point of view, as the roof was covered with stalactites, which could only have been formed when the Island was at a sufficient altitude to permit of the percolation of water through the roof, indicating a subsidence of at least 30 feet.

The 35 H.P. engine being ready for use by the end of February, 1867, the water was kept down by its aid to 34 feet below the sea level, without the assistance of the other pumps. The intention of Colonel Clarke at this stage of the work was to complete the caisson groove, invert, and about 40 feet of the dock lined ready for use (if circumstances should require it), leaving the remainder of the masonry lining to be completed at comparative leisure. This appeared to be quite practicable, the rock being so far of sound quality.

In the following month the pump-well reached to a depth of 43 feet, at which point so great an increase of water took place, that operations in the lower parts of the work were suspended, the water only being kept down to 34 feet, or 7 feet 6 inches above the bed of the invert. An additional portable engine of 12 H.P. was employed, and another of 20 H.P. ordered, which was ready for use in the following May. The latter was attached to one of Murray's chain pumps, 16 inches by 8 inches, and discharged 1,600 gallons per minute, 50 feet high, when making 40 revolutions per minute, with a pressure of steam of 30 lbs. These two engines were sufficient for the water in the dock, but that flowing into the entrance, outside the caisson groove, required the engines of 35 H.P., 10 H.P., and 8 H.P. for its removal.

In July the flow was gauged, and the total quantity was found to be not less than 5,725 gallons per minute, and the addition of a 30 H.P. portable engine was considered necessary.

The excavation at this period was, on the average per day, 600 tons of rubbish removed, and 8,000 cubic feet of rock quarried.

The cost of pumping was much increased, in consequence of the unusual scarcity of fresh water. The dockyard tanks were unable to continue the supply to the engines after June. The daily consumption was about 35 tons, increased towards the autumn to 60 tons, and nearly the whole of this had to be procured for several months from Dr. Normandy's condensing machines, which were erected for the purpose. The same means were adopted for relieving the wants of the inhabitants of the neighbouring cities, but the enlargement of the aqueduct, lately made by the Maltese government will, it is to be hoped, avert the recurrence of such a calamity. The cost of fresh water thus obtained during the year 1867 was £2,400 extra.

The temporary pump-well in the entrance, from which the greatest leakage proceeded, was filled up with concrete, and another one sunk upon the wharf, about 20 feet behind the coping, in such a position that the 35 H.P. marine engine could work the pumps in it as before, without being taken down and re-erected, which would have occupied valuable time. This new well was perfectly dry and free from fissures to a depth of 48 feet below the sea. The water was led to it from the entrance by a short adit.

In August the site of the invert and caisson groove, where very favourable rock was found, was excavated ready for "setting the first stone," which ceremony was performed by Vice-Admiral Sir Henry Kellett, K.C.B., then Admiral Superintendent. As the largest fissures were found near the centre line of the dock, 50 feet within the caisson, it was decided to lay in two lines of 12-inch cast-iron pipes below the masonry, through which the water from these fissures could be partially led to the pumps. These pipes are shown in the general plan, Plate 4. The outlets were provided with vertical disc valves, with screw adjustments, and were manufactured by Messrs. Aird and Son. They were carefully bedded in the solid rock with cement, and the top levelled up flush, to receive the masonry of the invert and floor.

In February, 1868, the removal of the rock round the main fissures (which had been left at 34 feet below the sea until the invert was set) was again proceeded with, but the discharge under so great a head continued daily to increase, and the two 12-inch pipes were found to be quite insufficient. By the 11th of March it was levelled to 39 feet, when the engines were again overpowered. Wedges were then driven in, but new openings were formed, which increased the evil. On the 1st April another foot had been gained; but as any obstacle opposed to the stream caused fresh discharges or jets at other places (owing to the friable and rotten character of the rock), it was necessary partially to suspend operations. The engines in use at this time amounted to 35 H.P. in the entrance, and 88 H.P. in the dock. In the meantime a 20 H.P. horizontal marine engine, by Penn, was obtained, and erected, with a centrifugal pump, by the 4th May, and two additional lines of 12-inch pipes were laid under the floor of the dock, drawing the water from the main fissure (General Plan, Plate 4). The pumping power now available was 143 H.P., the leakage being 7,500 gallons per minute, but towards the end of May the labour of keeping so large a number of engines in repair under incessant work became so great, that the water could not be lowered, for any practicable purpose, more than 32 feet below the sea level. To have obtained additional engine power from England would have required some months, during which a great outlay would have had to be incurred, or the works must have been wholly suspended at a critical point. These considerations led the Author to adopt the following expedient:—

The water was allowed to rise to 28 feet, to relieve the pressure, and a stage was formed over the main fissure. A guide box was lowered upon the fissure, and within the box a chisel, 21 feet long, was worked by a ringing engine, by which means a pit was cut in the rock, to a level of 43 feet 9 inches below the sea. This, being levelled and squared roughly by a diver, received a slab of limestone, 6 feet 6 inches by 3 feet 6 inches by 1 foot 5 inches, having a thick bed of puzzuolana under it, protected by canvas, secured to the slab (Plate 4). This being carefully set, the edges were filled in with wedges, which reduced the leakage perceptibly, and the slab could be exposed for short intervals, during which the centre courses of the floor could be set over it, the whole of the leakage passing freely below the masonry to the several pump wells. In July the masonry was sufficiently set to permit of the partial closing of the outlet valves, by means of the screws, and in the following month the pumping power was reduced from 143 H.P. to 103 H.P. The several valves were successively closed, as shown in the General Plan, Plate 4, and the upward pressure of the springs gradually brought upon the masonry without any leakage making its appearance. The entire leakage from the caisson, dock, sluices, and 236 lineal feet of culvert (having no masonry lining) was, on the completion of the works, less than 7 gallons per minute.

A return of the work performed by the pumping engines is given in the Appendix, page 367.

MASONRY, MORTAR, ETC.

The course adopted in setting the masonry was suited for the purpose of putting the dock into use at as early a date as possible, as before explained, viz., by completing the caisson groove and camber, the invert, and about 40 feet in length of the altars and floor. The keel blocks for the remaining distance were to be laid upon the natural rock; but as more time was available than was originally expected, the masonry was continued towards the head of the dock, to the width of nine of the centre courses of the floor, which were set by a traveller working along the centre line from end to end at a low level, as shown on the transverse section, Plate 4. When these courses were set, they formed the base for carrying a staging 48 feet in height, with corresponding staging upon the wharves; and two of Taylor's steam travellers were placed upon it, which continued the masonry nearly to the water line, above which ordinary sheers were used. The centre staging was 150 feet in length, of five bays, the back being taken down as the work advanced, and re-erected in front. The stones were delivered upon the wharves within reach of travelling cranes, three of which, also by Messrs. Taylor, were employed in stacking them.

The exposed or inner lining of the dock was formed of the hard crystalline limestone of the miocene rocks, composing the Maltese Islands, in blocks weighing from 3 tons to 8 tons. The backing was partly of an inferior quality of the same rock, and partly of that found suitable from the excavations (Plate 4 and Appendix). The lime was burnt in a kiln upon the works, and cost 4*s.* 6*d.* per cubic yard, slaked for use: it was obtained from the first quality of crystalline limestone, and possessed no hydraulic properties, being rich in quality. The puzzuolana was supplied from the caves of St. Paul, near Civita Vecchia. It was of a violet-red colour, and weighed, dry, 70 lbs. per cubic foot, the average price for which was rather less than 7*d.* After being passed through a fine sieve, it was mixed with ⅜ths of its bulk of slaked lime, and the mixture was then ground in a pan revolving under cast-iron edge rollers, driven by an 8 H.P. portable engine, the pan making about twenty-four revolutions per minute. The best mortar was ground in fifteen minutes. The quality improved with finer grinding of the puzzuolana, the density of the mortar being greater. The mortar weighed about 1 cwt. per cubic foot, but was inferior to Portland cement for water-tight purposes. The results of a series of experiments made by Mr. T. Lovell, M. Inst. C.E. (who superintended the works during the summer of 1867, while the Author was on leave of absence), are given, with others subsequently made by the Author, in the Appendix. The briquettes were 2¼ square inches in area, and were broken in tension, in order to compare with others made elsewhere, and the results are very favourable.

EXCAVATION OF ENTRANCE.

The centre line of the dock formed an angle of 28° with the old wharf line of the French Creek. The north entrance wall was thus 345 feet in length from the outer invert, and the south wall 136 feet, the skew width across the entrance being 240 feet. To inclose this with a cofferdam sufficiently large to enable the whole of the rock to be removed within it, to the required depth of 33 feet 6 inches below the sea, would have been very expensive; and as a matter of economy the dam was placed upon the sloping rock where its surface was about half that depth, and the rock was excavated in the ordinary manner, by pumping and quarrying, up to the dam. Plans and sections of this work are shown upon Plate 4.

The dam was shored from three temporary buttresses of rock and masonry; but as these buttresses, by exposure to the atmosphere, showed symptoms of weakness, they were also shored to the face of the north entrance wall. When the rock within the dam was removed to its full depth, the intention was to admit the sea, and remove the remainder (forming the support of the dam), by divers; but as the caisson was not completed, and its use was absolutely necessary, in order to protect the work within the dock, it was determined to excavate the rock beneath the dam in the following manner: Twenty-three parallel tunnels, or drifts, were driven in the rock at right angles to the line of the entrance, as far as the men could obtain access to the rock without cutting through the solid roof. This was executed without a great influx of water, although several large fissures were exposed, and had to be built up with masonry. These drifts were then connected by cross cuts, leaving the dam and the bed of the creek supported upon a series of rock pillars. These pillars are shown on Plate 4, and likewise the outline to which the rock was thus removed, and sections of the drifts and cross arches. By these means the quantity of rock to be removed subsequently by divers was much reduced, and the remainder was left in a more accessible condition for blasting.

Upon the completion of the caisson the sea was admitted, the dam was removed, and the mud was dredged from the rock. A careful survey had been previously prepared, from which a series of holes, 5 inches diameter, could be drilled in the pillars, &c., from a floating stage. All the holes are shown upon the plan of the entrance cofferdam, and also to some extent upon the section of the same, Plate 4. The charges were placed in tin cylinders, and were fired, frequently in groups, by a Wheatstone exploder. The rock was then slung by divers, and hoisted by steam power, the small stuff being filled into boxes. The depth for admitting the 'Minotaur' class of ships was attained by the end of September, 1870, four months after the completion of the caisson.

The rock buttresses had charges of 18 lbs. built in before the sea was admitted, but only one buttress was blown up in this way, as the vibration caused in the town of Isola was dangerous to the buildings, and lighter charges had to be used.

The Caisson.

The caisson and the penstocks were constructed by the Butterley Iron Company, under the supervision of Colonel Clarke, and the caisson is shown upon Plate 5. It is upon the sliding principle, a camber for its reception being provided upon the east side of the entrance. Its position nearly coincides with the salient angle of the Senglea bastion, 80 feet in height, and a tunnel was formed beneath it, in the construction of which, from the broken character of the rock, considerable difficulty was met with.

The caisson is 83 feet in length on the deck, 41 feet in height, and 12 feet 4 inches in width. The lower watertight deck is 21 feet below the top, and under this the water passes freely, the ends being open. In the side elevation (Plate 5) the caisson is shown in its place, and the dotted lines represent its position when in the camber. The upper deck has a vertical movement of 2 feet, and the handrailing is connected with it in such a manner, that it falls upon the deck when the latter is lowered. The deck is supported by seven pairs of vertical legs, hinged at the top to two longitudinal girders, which carry the cross girders of the deck, and moving longitudinally at the bottom (like pendulums), but supported upon the second deck (when vertical) upon two rollers attached to them. The rollers are connected together by two T irons, or draw bars, which, on being pushed or pulled from the end, cause the legs to assume an inclined position when the deck has to be lowered, or a vertical position when it has to be raised. The draw bars are attached at one end to two endless chains, working on each side of the camber. These chains are set in motion by gearing at the end of the camber, driven by shafting from the drainage engine. The movements are under the control of a man at the friction clutch, and are made with ease and rapidity. The deck is counterbalanced by boxes of stone suspended within the caisson. In repairing the caisson, after being placed in the camber, a temporary dam is made across the end of the camber, by lowering timbers down two grooves prepared in the sides for that purpose. The timbers are supported in the centre by a vertical post slipped into a socket at the bottom, which is also strengthened by wrought iron shores or stays to the sides, as shown. The camber is then emptied by means of a small penstock. The flotation of the caisson, according to the slight variation of the water level, is adjusted by 35 tons of water ballast beneath the upper deck, which is increased or diminished, as required. The caisson contained 22 tons of cast iron, 255 tons of wrought iron, and 515 lbs. of brass. The machinery in the camber contained 14·7 tons of cast iron, 13 tons of wrought iron, and 579 lbs. of brass. The fixed deck over the camber contained 15·7 tons of wrought iron. The penstocks and fittings contained 38·15 tons of cast iron, 4·77 tons of wrought iron, and 1,538 lbs. of brass. The caisson and camber contained also 617 cubic feet of oak and green-heart timber, and the fixed deck 256 cubic feet of oak.

PUMPING ENGINES.

The machinery for emptying the dock (Plate 6) consists of a pair of 60 H.P. high pressure non-condensing horizontal engines, having a crank shaft 6½ inches in diameter, driving three centrifugal pumps, by means of a heavy mortice wheel, 10 feet 8 inches in diameter, gearing into three pinions, 2½ feet in diameter, keyed upon the three pump spindles. The engines are constructed on one bed, and have a pair of cylinders 27 inches in diameter, with a length of stroke of 3 feet, and they work at 45·2 revolutions per minute, which is equal to 271 feet per minute. The steam, of a pressure of 50 lbs., is cut off at half stroke, and the indicated power amounts to 400 H.P. Two of the three centrifugal pumps have pipes 30 inches in diameter, and one has a pipe 36 inches in diameter. Each pump revolves at 240 revolutions per minute, and the smaller pumps discharge each 14,000 gallons, and the larger one 20,000 gallons, for the first half of the lift of 16 feet. The large pump is then thrown off, and the smaller pumps are kept on to the bottom of the dock. This is equal to a lift of 32 feet, but it has since been increased to a greater depth. The two pumps discharge about 10,000 gallons per minute each when working at the bottom of the dock, which is equal to a duty of 50 per cent. of the indicated H.P. of the engines. The engines take 15 per cent., and the gearing 10 per cent., leaving a useful effect of 75 per cent. for the pumps. The engines are driven by three Cornish boilers, two of which are 6 feet 6 inches in diameter and 30 feet long, and one is 6 feet 6 inches in diameter and 26 feet long.

The pumps are all driven together when the dock is full, but after the water is lowered 11 feet one of the pinions is thrown out of gear, and at 23 feet another is detached, the pumping being completed with one only. The quantity of water pumped is 7,077,115 gallons in 4¾ hours. The engine commences with twenty revolutions per minute, and increases in speed to the completion of the work, which requires fifty-two revolutions per minute. The pump spindles revolve five and a half times faster than the engine. The whole of the engines and pumps are placed within a cast-iron tank sunk into the rock, and the three discharge pipes, of 36 inches in diameter, pass through the side, and deliver the water into a canal, which discharges it into the entrance. The three suction pipes pass through the bottom of the tank, below which is the well, 16 feet in diameter, and 50 feet below the sea, connected with the dock by a culvert cut in the rock, 236 feet long, and 6 feet by 5 feet in section. The drainage of the dock while in use is effected by a 30 H.P. engine, which also works the machinery for the caisson and the hydraulic pump for the penstocks.

The whole of the above-mentioned machinery was made by Messrs. Gwynne and Co., of the Essex Street works.

The communication is accompanied by a series of drawings and diagrams, from which Plates 4, 5, and 6 have been compiled.

[APPENDIX.

TA.

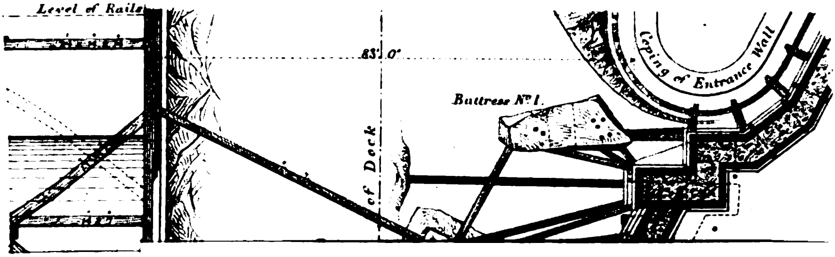
Level of Rails
83' 0"
of Dock
Buttress No. 1.
Coping of Entrance Wall

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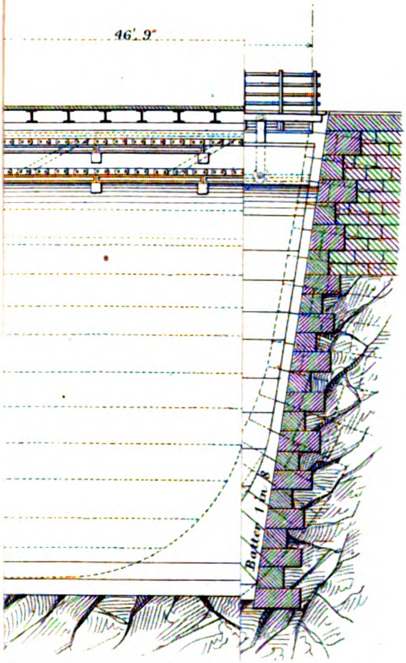
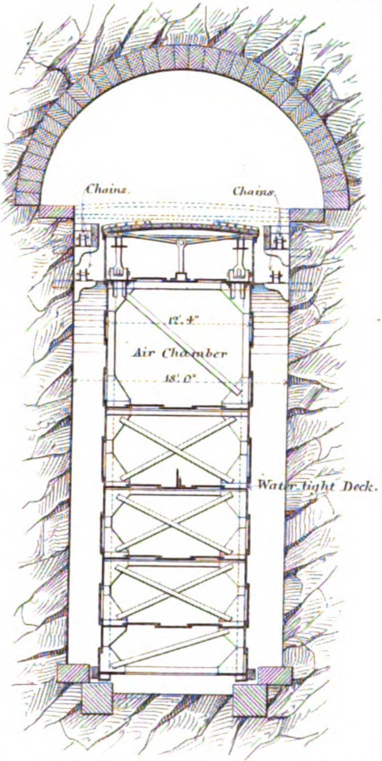
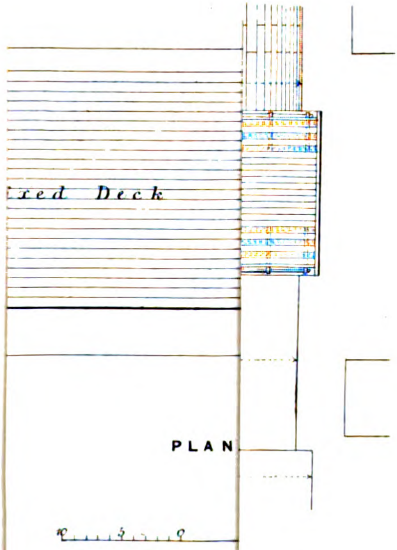
PLATE 5.


46'. 9"
Batter 1 in 8

EVATION OF CAISSON A


Chains.
Chains.
12'. 4"
Air Chamber
18'. 0"
Water-tight Deck.

TRANSVERSE SECTION OF CAISSON IN THE CAMBER.
(With Deck and Handrail lowered.)

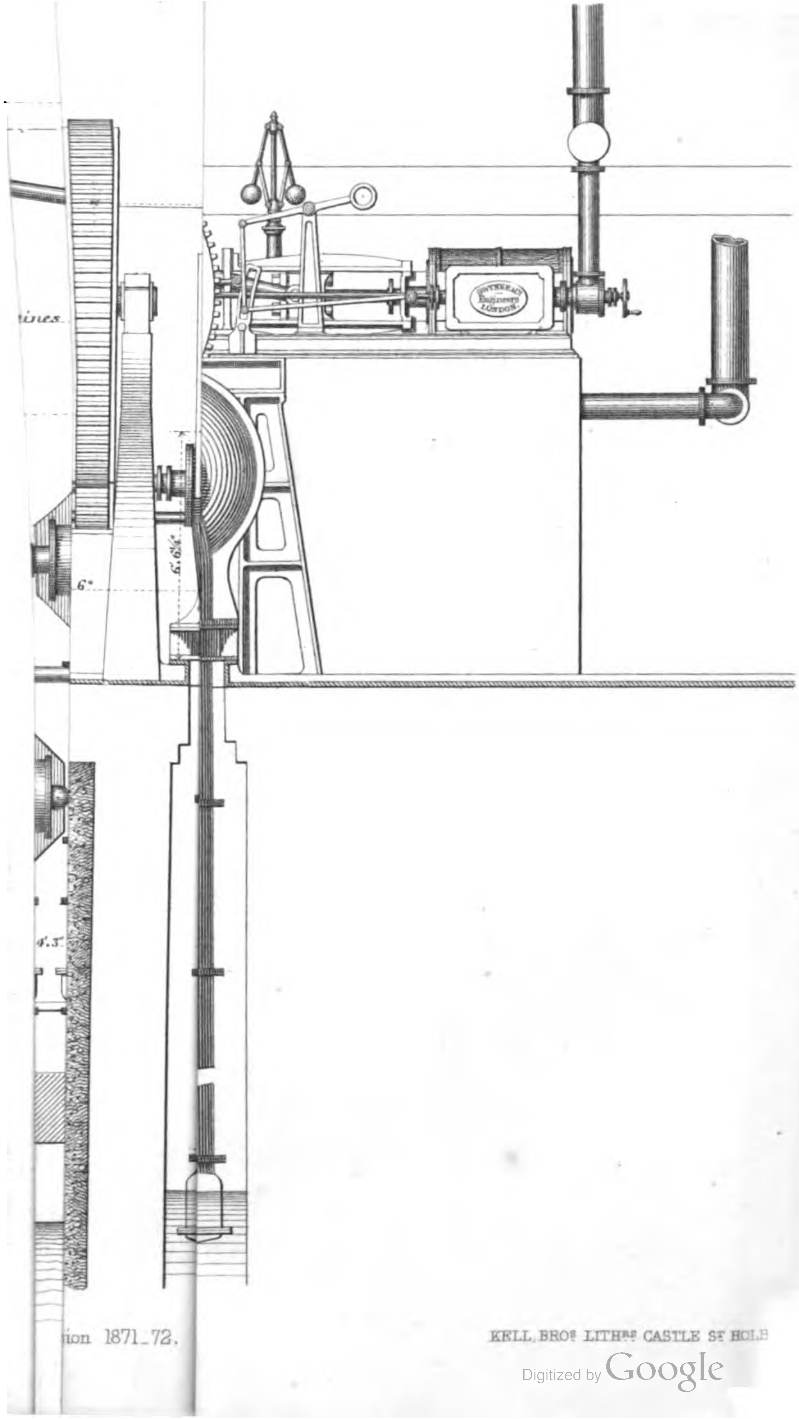


PLAN

Minutes of Proceedings

KELL BROS LITHRS CASTLE ST

A. **PLATE 6.**


ines
GWYNNE & Co
Engineers
LONDON.
6'
6'.6½"
4'.3"

ion 1871_72.

KELL, BROS LITHRS CASTLE ST HOLB

APPENDIX.

EXPERIMENTS UPON THE STRENGTH OF PUZZUOLANA MORTAR, ETC.

Number of Experiment.	Proportions of Materials.		Age in Days.	B. W. in lbs., and area, 2¼ sq. in.	Remarks.
1	Lime, fresh, 1.	Puzzuolana, 2	12	91	Kept dry.
2	Ditto.	Ditto	12	105	Ditto.
3	Ditto.	Ditto	18	175	Kept in sea.
4	Ditto.	Ditto	18	188	Ditto.
5	Ditto.	Ditto	18	196	Ditto.
6	Lime, burnt 2 months and fresh slaked, 1. Puzzuolana, 2.		18	189	Ditto.
7			18	190	Ditto.
8	Ditto.	Ditto	18	221	Ditto.
9	Lime, 3 months burnt and fresh slaked, 1. Puzzuolana, 2.		18	189	Ditto.
10			18	211	Ditto.
11	Ditto.	Ditto	18	203	Ditto.
12	Ditto.	Ditto	28	126	Kept dry.
13	Fresh lime, 1.	Puzzuolana, 2.	29	161	Ditto.
14	Ditto.	Ditto	29	180	Ditto.
15	Ditto.	Ditto	29	334	Ditto.
16	Ditto.	Ditto	30	182	Kept in sea.
17	Ditto.	Ditto	30	175	Ditto.
18	Lime, 3 weeks slaked, 1.	Puzzuolana, 2	30	450	Ditto (extra ground).
19	Fresh lime, 1.	Puzzuolana, 2,	38	161	Ditto.
20	Ditto.	Ditto	38	225	Ditto.
21	Ditto.	Ditto	41	305	Ditto.
22	Lime, 4 weeks slaked, 1.	Puzzuolana, 2	50	277	Ditto.
23	Ditto.	Ditto	50	415	Ditto.
24	Lime, 1 week slaked, 1.	Puzzuolana, 2	63	319	Ditto.
25	Ditto.	Ditto	63	298	Ditto.
26	Ditto.	Ditto	63	312	Ditto.
27	Lime, slaked 1 week, 1.	Puzzuolana, 2	69	417	Ditto.
28	Fresh lime, 1.	Puzzuolana, 2	82	105	Ditto.
29	Lime, slaked 4 weeks, 1.	Puzzuolana, 2	82	161	Ditto.
30	Ditto	Ditto	21	105	Ditto.
31	Fresh lime, 1.	Puzzuolana, 2	82	203	Ditto.
32	Ditto.	Ditto	365	324	Ditto.
33	Ditto.	Ditto, 1½.	269	373	Ditto.
34	Fresh lime, 1.	Puzzuolana, 1½	269	337	Ditto.
35	Ditto.	Ditto, 1⅓	92	366	Ditto.
36	Ditto.	Ditto	92	321	Ditto.
37	Ditto.	Ditto	279	286	Ditto.
38	Ditto.	Ditto	279	358	Ditto.
39	Ditto.	Ditto	251	305	Ditto.
40	Ditto.	Ditto	251	284	Ditto.
41	Ditto.	Ditto	251	291	Ditto.
42	Ditto.	Ditto, 1⅓	304	389	Ditto.
43	Ditto.	Ditto	304	340	Ditto.
44	Ditto.	Ditto	304	319	Ditto.
45	Ditto.	Ditto	365	324	Ditto.
46	Ditto.	Ditto	365	384	Ditto.

EXPERIMENTS UPON THE STRENGTH OF PUZZUOLANA MORTAR, ETC.—*continued*

Number of Experiment.	Proportions of Materials.	Age in Days.	B. W. in lbs., area, 2¼ sq. ins.	Remarks.
47	Lime, slaked 4 weeks, 1. Puzzuolana, 1. Coal ashes, 1	16	20	Kept in sea.
48	Lime, slaked 1 week, 1. Puzzuolana, 1	28	269	Ditto.
49	Ditto. Ditto	28	225	Ditto.
50	Ditto. Ditto	28	312	Ditto.
51	Ditto. Ditto	28	119	Kept dry.
52	Ditto. Ditto	28	319	Ditto.
53	Lime, slaked 4 weeks, 1. Puzzuolana, 1	18	154	Kept in sea.
54	Ditto. Ditto	18	196	Ditto.
55	Ditto. Ditto	18	182	Ditto.
56	Ditto. Ditto	18	175	Ditto.
57	Ditto. Ditto	18	210	Ditto.
58	Ditto. Ditto	18	210	Ditto.
59	Fresh lime, 1. Puzzuolana, 1 . . .	18	161	Ditto.
60	Ditto. Ditto	18	182	Ditto.
61	Fresh lime, 1. Puzzuolana, 1¾, and sharp sand, 1.	92	145	Ditto.
62		92	160	Ditto.
63	Fresh lime, 1. Puzzuolana, 1¾, and sharp sand, 2	92	162	Ditto.
64		92	204	Ditto.
65	Blue Lias lime, 1. Puzzuolana, 1 . .	60	205	Ditto.
66	Ditto. Ditto, 2	60	207	Ditto.
67	Ditto. Ditto	60	149	Ditto.
68	Fresh lime, 1. Puzzuolana, 1¾, and Portland cement, 2	61	473	Ditto.
69		61	472	Ditto.
70	Fresh lime, 1. Puzzuolana, 1¾, and Portland cement, 1	61	345	Ditto.
71		61	310	Ditto.
72	Fresh lime, 1. Sharp sand, 1	365	153	Kept dry.
73	Ditto. Ditto	365	109	Ditto.

NOTE.—In a few of the above experiments the mortar was specially prepared for the purpose; but the majority of them were taken from the mortar as it was found in use by the masons at the time.

COST OF STONE SUPPLIED BY CONTRACTORS.

Delivered on the Works, scappled to dimensions.

Sizes of Blocks.	Crystalline Limestone. First Quality.	Crystalline Limestone. Second Quality.	Soft Calcareous Sandstone. Third Quality.
	s. d.	d.	d.
Blocks not exceeding 5 cubic feet . . .	0 7	3	1⅛
Ditto from 5 to 10 cubic feet	0 10	4	1⅛
Ditto from 10 to 15 ,, ...	1 2	5	1⅛
Ditto from 15 to 20 ,, ...	1 5	6½	1¾
Ditto from 20 to 25 ,, ...	1 9	8	1⅞
Ditto from 25 to 30 ,, ...	1 10	8½	2
Ditto from 30 to 35 ,, ...	1 11	9	2⅛
Ditto from 35 cubic feet and upwards .	2 2	10	3

Return of the Annual Number of Hours worked by the Pumping Engines.

(Stoppages for repairs not included.)

Description of Engine.	Years.					Total Hours for each Engine.
	1866.	1867.	1868.	1869.	1870.	
8 H.P. (A) . .	1,900	5,331	2,709	4,653	1,618	16,211
10 H.P. . . .	1,167	6,103	6,249	5,972	1,495	20,986
35 H.P. . . .	..	7,207	7,616	746	..	15,569
12 H.P. . . .	..	5,976	6,261	4,784	3,131	20,152
20 H.P. (A) . .	..	4,813	7,510	5,412	2,686	20,421
8 H.P. (B) . .	..	1,904	4,342	3,302	2,775	12,323
30 H.P. . . .	..	..	4,963	5,825	3,292	14,080
20 H.P. (B) . .	..	..	2,475	571	..	3,046

Approximate total for one nominal H.P. = 1,960,921 hours.

[Mr. Redman

Mr. Redman remarked that, almost coincidently with the commencement of this work, a Paper was read by Mr. Edwin Clark[1] describing the mode adopted by him for raising vessels out of the water, under exceptional conditions; and only last session a Paper had been read by an American Engineer,[2] upon the dock at Po under conditions similarly antagonistic to a graving dock.

After due inquiry the authorities appeared to have reverted the stereotyped form of graving dock in England, which was admirably adapted for the Mersey with a variation of 30 feet, and for the Thames of 20 feet of tide. But on the tideless shores of the Mediterranean, it might have been supposed that all the conditions were in favour of the modern adaptation; more especially as this work, however well-executed and superior in character, had involved the expenditure of a very large sum of money. It was stated that the dock and entrance had cost £150,000, that it had taken six years in construction, and certainly this long period, and the fact that the dock itself was only capable of receiving one vessel at a time, were elements in the consideration of the great cost of this work. He had on former occasions given the cost of docks in various places. On the Thames the dock value, taking the sectional accommodation or contents of the dock below the flotation level, varied from £1 to £1 10s. per cube yard; and in the case of the Trafalgar dock at Woolwich Dockyard, which was a most extravagant work in every respect, where there was an addition of 50 per cent. in the depth of foundation, the cost of the dock amounted to £4 per cubic yard of internal accommodation; and the Boston dock in the United States cost rather more. The Somerset dock, excavated in rock, and faced with ashlar, cost from £3 to £4 per cubic yard of sectional accommodation, inclusive of the cost of the entrance necessary for the approach to the dock, but not adding to its docking capacities. If the cost of the entrance were deducted the cost would be nearly one-half. (*See note in next page.*)

The outline was on the type of the old Liverpool dock—straight sides as contrasted with a section less highly inclined and more parallel to the ships' sides. The most important advantage of that was that it reduced the first cost, inasmuch as the amount of excavation and the expense of pumping were less; secondly, the amount of pumping each time a vessel was docked was reduced, and the trouble and cost of docking was lessened, as shorter shores were sufficient for sustaining a vessel; but it had this disadvantage, that the space between the inside of the dock and the skin of the vessel was so small, that the light for working at the bottom of the ship was reduced.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., page 292.

[2] *Vide* Ibid., vol. xxxii., p. 65.

This dock, in many respects, was similar to the Liverpool docks and to some on the Thames. In all its features it presented the same characteristics. The docks on the shores of the United Kingdom were drained into a river or tidal sea; and the early dock-builders of Liverpool and London tilted the dock head upwards from the river into which the dock drained. In this case, however, with a constant head of water outside, there would be no advantage in that respect, because the water must be pumped out every time a vessel was docked. The dock at Malta might have been drained either towards the head or stern, or from the centre towards the head or stern, enabling a reduction to be made in the amount of excavation in the bottom. No doubt the work itself was a first-class one; and it would leave as indelible footprints of Saxon dominion in Malta as had been left by that remarkable brotherhood the ancient military and semi-monastic order of the Knights of St. John.

Mr. **Hemans**, Vice-President, observed that the method of excavating beneath the cofferdams into the open sea and leaving a roof to be afterwards blown up by electric apparatus, in sections, was novel and deserved high credit. The ordinary caisson was an oblong vessel which was grounded against a sill, and kept tight by timber sides; but this seemed to be a trough running upon rails, and he did not understand how the caisson was kept tight.

Note.—The following statement of the cost of graving docks might prove interesting. The greater depth and difficulty of the foundations of some as compared with others would materially affect the comparison.

Depth on the Sill in Feet.	Site.	Material.	Cost per Cubic Yard, Sectional Capacity, below Flotation Level.
16 to 20	Thames	Timber and Brick	10*s.* to £1.
	Naval Arsenals	.. ..	£1 18*s.* to £2 10*s.*
27	Thames Dock Co.	Brick and Stone	£1 18*s.* 6*d.*
	Sunderland	Rock-faced	£1 7*s.* 8*d.* to £1 9*s.*
25	Southampton	Brick	£2 to £3
26	Woolwich	Stone	£4 to £4 16*s.* 5*d.*
	Somes, Blackwall	Brick	£1 1*s.* 0*d.*
	Boston, U.S.	.. ..	£4 11*s.* 0*d.*
27	Birkenhead	.. ..	£1 17*s.* 0*d.*
	Malta, Old Dock	.. ..	£3 14*s.* 0*d.*
33½	Do., Somerset	.. ..	£3 6*s.* 8*d.*
	Do., without Entrance	.. ..	£2 0*s.* 0*d.*

Mr. Beardmore said he apprehended the caisson rolled out o rails, and then took a flat bearing against the cill. He suppos that its action was quite independent of flotation, which was great advantage. The excavation of the rock under the sea outsi the cofferdam was one of the most remarkable feats that had eve been described before the Institution.

Mr. J. G. C. C. Godsman said, having visited Malta two or thre times, he considered that the class of dock and site selected were possibly those best adapted to all the circumstances of the case. It had been objected that the more modern type of floating dock should have been adopted, and special reference had been made to Mr. Edwin Clark's Hydraulic Lift dock, but he thought such objections were without foundation. The land surrounding Malta Harbour was, for the most part, high and rocky, with a very small portion of that low lying land which rendered the system of Mr. Clark so peculiarly applicable to the banks of the Thames, and to an extensive commercial trade. The great advantage of the hydraulic lift was, that by means of it a number of vessels could be floated off of it on pontoons into a shoal-water pond or lagoon; the only limit, so to speak, of the number of vessels being the time it took to lift and remove them, and the area of accommodation in the lagoon. In the operations of cleaning the bottom and painting, a vessel on a pontoon had an advantage over one in a graving dock, owing to the greater exposure to the drying action of the wind. The proposed dock was not, however, intended for a large commercial fleet, but for a limited number of iron-clads. He had seen a vessel docked in the graving dock built from the designs of the late Mr. Scamp, and he considered it to be very available and useful for the purpose.

Mr. Stephenson, Vice-President, remarked that he was particularly familiar with dock construction, and had paid a good deal of attention to the mechanical appliances for opening the gates. As far as he could judge, from a cursory observation of the model of the moving machinery, the power was given out from the handle, as seen in the model. It seemed to him there were several matters in respect of such an arrangement which required explanation. In the first place, the power was given out at right angles, by means of a longitudinal shaft. If the handle had been placed on the shaft, it seemed probable that the whole power could have been at once applied to the main shaft direct; and this seemed, in the absence of further information, to be preferable to any kind of bevel-gearing, which was the most costly and dangerous, as far as breakage was concerned, that could be applied for the purposes of transmitting power. This was especially the case in cotton factories, where there was no class of wheel so liable to breakage as bevel wheels; and he could not understand why that plan had been adopted in the present instance.

The Gwynne pump was one that could be, and was, largely employed for special purposes; but it was a serious question, whether it was the right one to use in conjunction with the compound marine engine, now being made for vessels undertaking long voyages; though for short voyages it was very suitable. In engines that he was now building for very large ships, he found it essential to keep the old-fashioned pump in addition to the new one, in case of the break-down of the latter. It was only fair to say, that the Gwynne pump had the advantage over the ordinary pump attached to the engine, of getting up a vacuum in the condenser before the main engine started. He believed the Gwynne pump had been, in most cases, unfairly used, especially in long ocean voyages. He knew that for the purpose of condensing the steam in the condenser, a Gwynne pump had been started working at Liverpool, and had never ceased till the ship arrived at Calcutta, except in the event of some mishap to, or break-down of the vessel. The advantage of this pump was its high velocity of working; but when machinery had to travel at a high velocity for weeks together, it was impossible for any engine-man, however experienced and clever he might be, to see that all the parts were kept in proper repair; and that was the case with the Gwynne pump, when it was worked for weeks or months together. A locomotive might be run from London to Rugby, or 50 or 60 miles further; but after it had traversed, say 200 miles, it became a question whether or not it would break down, and the moving parts could not be examined. So with the Gwynne pump, which moved at a higher velocity than a locomotive.

Mr. W. H. Allen said, Mr. Stephenson's observations had reference rather to the work of the pumps in connection with condensation in marine engines than to the work performed at this dock. The former were small engines driven at a high velocity. Pumps of large diameter gave out a considerable percentage of duty. The great advantage of the centrifugal pump was its cheapness. Other descriptions of pumps for doing the same work at the Malta dock would have cost ten times the money.

Mr. J. Grant observed, in reference to the mortar and puzzuolana used for the dock, that the strength of both in sea water was given; and increased with age, as ought to be the case with good mortar.

In one series of experiments beginning with a breaking weight of 154 lbs., at eighteen days the strength increased to 345 lbs., and even 472 lbs. at the end of sixty-one days. The testing samples appeared to have been taken, in most cases, from the mortar actually used. In only a few cases did the experiments appear to have been made with mortar prepared for the purpose. Had the Author been present, he would have asked whether some economy might not have been effected had it been possible to get the caisson ready earlier, and shut out the water from the excavation, which had apparently to be done under great difficulties. The work would probably have been kept dry at a smaller expenditure for pumping power.

Lieut.-Col. A. CLARKE, R.E., C.B., observed that the subject of graving and floating docks, and of hydraulic lifts, had been exhaustively discussed at the Institution a few years ago. He was not an opponent of either the floating dock or the hydraulic lift; and he had built, for special purposes, the largest floating dock in the world, and had advised her Majesty's Government to encourage, by a loan, the hydraulic lift at Malta. He therefore trusted he should not be considered wedded to the old system. But the necessities which had arisen with regard to Bermuda (where a floating dock was employed), and which also suggested an hydraulic lift in the commercial harbour at Malta, did not apply to this particular case. The Engineer in these matters was, to a great extent, in the hands of the shipwrights; and for the ships of large size and tremendous weight of many of those in the Royal Navy, it was not considered by the shipwrights that the hydraulic system would be applicable. One of the objections raised to the old form of graving dock was the advantage which it was said the hydraulic lift had, viz., that with it numerous vessels could be lifted and placed on trays, which could not be done in a graving dock. That was not the case. The graving dock could be made available for placing ships on trays just as well as the hydraulic lift. The trays had only to be placed in the graving dock, and the ships upon the trays, as upon the ordinary docking blocks; and thus the ships could be transferred to trays as well in the dock as by the lift. The difficulty in dealing with the tray system—which was really the most prominent advantage of the hydraulic lift—was that of shoring heavy ships. Shipwrights hesitated to limit themselves, for heavy ships, to the bilge shores, and to shoring at the severe angles which were entailed by the trays, where breast shores could not be used, and until that difficulty was overcome the application of the hydraulic lift could not be established. Besides, it was essential that the dock destined for damaged and wounded ships after action should admit of the vessel being docked immediately, and that this should be practicable under all conditions of weather. In the consideration of the question of the hydraulic lift, it occurred to him that there were days when a ship could not be got upon a lift; and that circumstance, combined with the fact of his being unable to command a site in Malta in which it was certain that, under all conditions of weather, ships could be lifted with safety, led him ultimately to abandon the idea of a floating dock as well as the hydraulic lift. It had been stated that this dock was expensive, in comparison with docks elsewhere. An hydraulic lift, to have done what this dock could do, would probably have cost considerably more than this dock had cost, and would not have had its peculiar advantages.

With regard to the selection of the site, between the Dockyard and the French Creek a peninsula rose up from 70 to 90 feet high, and it was argued that by levelling that rock to 5 or 6 feet above the water level an amount of excavation, which cost from £15,000 to £20,000, had been required, and that this expense might have been avoided. But there were local as well as strong political reasons which rendered it necessary that the present, and, as he considered, most favourable, site should be selected. He was tied by this fact—the French Creek was, when he selected the site, the home and refuge of the whole of the commercial navy frequenting Malta, and this had, by a previous arrangement, to be turned out of that creek, and sent to seek a resting-place in the Grand Harbour and the Marsa. And as he could not touch the water of the French Creek till the Marsa was ready for the reception of the vessels, the construction of a dock in the French Creek would have been postponed for three or four years, had he selected a site for it encroaching upon the water space of that creek. Another dock had almost been commenced in the north-west basin at the harbour extension. The objection to that was, that whilst the naval establishment was in the Dockyard Creek, this dock would have been a great distance from it, and close to the Grand Harbour, where the merchant shipping would all be. There would have been constant chances of difficulty and collisions with the mercantile navy, besides the absence of economy, as the dock would thus have been at a distance from the Government sources of manufacture. On the site of the present dock there was at that time a fortification, but he attached little value to the fortifications: they were obsolete and useless, and he was perfectly indifferent to their destruction. Again, vessels coming into the French Creek from the Grand Harbour could steam directly into the dock without getting out a hawser, and without any difficulty, the dock being at a convenient angle to the line of the stream.

He had placed the dock so far inland to get it as near the old dockyard as possible, and to secure, when a ship came in, that she should be in still water, and also to obtain wharfage space along which her Majesty's ships might lie outside the dock.

He did not claim anything new in the section or form of the dock. He believed it was good, and he did not advocate changes as long as old things were good. It was, however, one of the largest and deepest docks in the world, the ordinary depth of water being 33½ feet over the sill.

An opinion had been expressed that if he had placed the caisson in position earlier the work would have been less costly, because the pumping, it was assumed, would have been less. But the fissure through which the water came, instead of being in line with the length of the dock, traversed across it, which enabled him to control the water better than if it had traversed the length of the dock; therefore there would have been no economy in putting the caisson in place earlier. No doubt, as compared with some of the docks in the Thames and in the Mersey, the dock was an expensive one; but there was a vast difference between building a dock in a depth of only 22 or 24 feet of water, and where there was a depth of 33 feet. The greater the depth of the dock, the greater was the expense of the pumping. He now regretted, however, that he did not first sink a well, and put up powerful pumping engines. What tended in a great degree to make the work expensive was the maintenance of eight or ten small engines to keep the water down. If he had at first erected a permanent well and engines, he believed the expense of the dock would have been considerably less; for while the total cost of the dock and entrance was about £150,000, the charges for temporary pumping and other machinery, exclusive of labour, amounted to £8,500, for coal £20,000, and for oil £1,600; so that a large portion of the expense was incurred in dealing with the water. Generally where works of this kind were to be undertaken in connection with water, the first expense, large as it might be in applying pumping power of a permanent character without adopting temporary expedients, was the best economy. Another matter, which rendered the works apparently costly, was the difficulty of getting rid of the materials from the excavations. In an island of limited extent like Malta, ground for depositing spoil was hard to obtain. He had either to convey in barges the débris to sea, or to cart it away to a distance at great expense. The cost of removal by barges to sea alone was £10,000. He afterwards induced the Island Government to grant him ground, where the whole of the remainder of the débris was carted, at the cost of £9,000 more. These were difficulties met with in dealing with a military port; and all the peculiar circumstances of the case must be taken into consideration, before a judgment could be pronounced whether the works were costly or not.

The general reason which led him to adopt the sliding caisson was, that while the first cost of the caisson was greater than that of gates, with the sliding caisson in docking a ship the people engaged had only one thing to look after. Floating caissons entailed a number of people to look after them, and after the ship too. With sliding caissons, the cambers and stops could not always be kept entirely free from mud; and in the case of those caissons, the sea must be tolerably free from mud and kindred deposits.

At Chatham, with the muddy waters of the Medway, he had not used these caissons; but while the expense was in the first instance, no doubt, greater, because the cost of the additional camber and machinery was greater in the first instance, the difficulty of working the caisson was very considerably less than that of the ordinary ship caisson, which took twenty-five or thirty minutes or more to manipulate, whilst this caisson was taken out and put back into place in less than five minutes. It was easily handled and readily repaired on the spot. It also formed the best system of roadway, capable, if necessary, of carrying a railway train upon it, besides other advantages.

January 30, 1872.

JOSEPH CUBITT, Vice-President,
in the Chair.

No. 1,318.—"On the Value of Water, and its Storage and Distribution in Southern India."[1] By GEORGE GORDON, M. Inst. C.E.

IT is not intended in this Paper to discuss the value of water in its widest sense, or to consider the indirect benefits which would follow the control and abundant distribution of the enormous wealth of water now, for the most part, rolled into the sea—benefits among which are to be reckoned, the prevention of famines and of scarcity in the districts concerned, as well as the permanent improvement of agriculture, and the numberless social and political advantages resulting from enhanced prosperity and increase of population.[2] The object of this communication is rather to afford, from well-authenticated data, some means of estimating the more direct profits of works of irrigation which have been, or could be, undertaken as commercial speculations in the present day. For this purpose some preliminary remarks on the works employed for storage and distribution, on the ancient and modern systems, seem needful.

I. TANK IRRIGATION.

The existing tank irrigation dates chiefly from ancient times. The number of tanks, large and small, in Southern India is enormous; some of them attain the dimensions of lakes, others suffice only for the irrigation of a few acres. They may be divided into three classes: 1st. Where advantage is taken of a narrow gorge in a range of hills, to close the passage of a river, by a dam or embankment of considerable height, and so to convert the valley above into a lake. 2nd. Tanks formed by the construction of embankments across one or more streams in the flat country, this class being often of considerable superficial extent, but comparatively shallow. 3rd. Such as may be considered intermediate between the 1st and 2nd classes.

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[1] The discussion upon this Paper occupied portions of three evenings, but an abstract of the whole is given consecutively.

[2] The population of the Bellary district, which is unirrigated, is 109 to the square mile. The irrigated districts of Tinnevelly and Tanjore support populations of 343 and 442 to the square mile respectively.

Most of the tanks of the 1st class are now ruined. In many cases the earthen embankment has been breached, in consequence of the water finding a passage along the outside of the discharge culvert, which was generally placed under the embankment, and not in a tunnel at a distance. The dams were, it is believed, invariably made of earth, without any puddle core, and the inner slope was always protected with heavy stone pitching.

The Author is not aware that high masonry dams were ever constructed for storage purposes in Southern India; but there is, near Ahmednuggur, in the Bombay Presidency, an instance of the combined use of masonry and earth, in a dam for a large ancient tank, described by Colonel Fife, R.E., in the Roorkee Prof. Papers, Vol. V. This dam, however, was never finished.

The number of disused tanks, of all sizes, is very remarkable. Many of these are not breached, but the discharge culvert is left open, and no water is collected. In many cases this is, probably, owing to the bed of the tank having been gradually raised by silting, and converted into so productive a soil, that it yields as much as, or more than, could be obtained by means of the diminished quantity of water applied to the comparatively barren soil below the tank; but generally it results from the ascertained fact, that the rainfall in some districts has materially diminished (markedly so even within the memory of man), on which account the tanks would never fill, and in most years would receive so small, and especially so uncertain a supply, as to render wet cultivation to any large extent not to be depended on. Dozens of such abandoned tanks are met with in the hilly parts of the Ceded Districts; as, for instance, along the foot of the inner slope of the eastern Ghâts, where, in many cases, both the bed of the tank and the cultivated land below it have reverted to jungle.

A good specimen of the tanks of the first kind is one which the Author was deputed to examine a few years ago, with a view to its restoration. A short description of it will afford an idea, both of the construction of ancient works and of the untrustworthy nature of the data which old works seem to afford for the construction of new works.

Description of the Mudduk Masoor Tank (*Plate* 7, *Fig.* 1).

This great work is believed to have been constructed under the Annagoondy dynasty, about four centuries ago. It was formed by an embankment, resting on the sides of a narrow gorge through which the river Choardy passed, supplemented by two bunds, or dams, on saddles in the range of hills; that on the east being 1,350 yards, and that on the west 670 yards from the main bund. The length of the main bund is 550 yards on the top. The inside slope, of 2½ to 1, in some parts 3 to 1, was revetted with large stones, up to a cubic yard in bulk. It is from 945 to 1,100 feet broad at the base, and is now from 91 to 108 feet high. There was a sluice under the dam at the east end about the level of the ground. The dam is composed of a strong red earth, with a considerable admixture of gravel, taken from the sides of the hills on which it rests. The east supplemental bund has its base 74 feet above the sluice in the main bund, and had also a sluice under it at the ground level. The west supplemental bund, the breaching of which destroyed the tank, seems to have been of similar construction to the others, and its base was perhaps 50 or 60 feet above the bed of the tank. There is no trace of any waste-weir, and it is probable that the want of this was the cause of the ruin of the tank. On the main bund there are what seem to be traces of the water having topped it, and having cut into the rear slope in two deep gullies. The west bund had, probably, a sluice in it which weakened it, as cut stones were found in the river some way down. After this bund was breached, the water cut into the ground on which it stood to the depth of 100 feet, and would have completely emptied the tank but for a reef of rock some distance from the dam, on the inner side, which now causes a waterfall 25 to 30 feet in height, and retains about 10 feet of water in the tank. On this reef a weir has been built.

From the heights of the dams and the levels of the sluices, it is probable that the depth of the tank was 90 or 95 feet, and at that level its area would have been 40 square miles, and its contents about 1,400 million cubic yards of water. The drainage basin is about 500 square miles, and three-fourths of it lies within the jungly district containing the spurs of the western Ghâts. It is found, from observations of the discharge of the river, that a good average monsoon supply would not exceed 668 million cubic yards, or 16 inches running off. It is not probable that the average annual rainfall so near the Western Ghâts has diminished much, although it may, to some extent, from land having been cleared of jungle; nor is there anything to show that the ancient tank filled every year. The difference between the present supply, and what it must be supposed to have been when the tank filled and was breached (even supposing that to have occurred in an exceptional year) is probably owing, in part, to the construction of small tanks on some of the feeders. The tank, as proposed to be restored, would have contained about 644 million cubic yards; and the results are given subsequently. As regards capacity, this is the largest reservoir in Southern India of which the Author can find any record.

Tanks of the 2nd Class: Flat-country Tanks.

These are so numerous in some districts that, looking at a map, it would appear as if as much land is occupied by tanks as is left to be irrigated by them; and where the tanks are very shallow, this would be necessary for complete irrigation. But in reality, many of these tanks are breached or abandoned, and their beds cultivated. The embankments of flat-country tanks are often of great length, not unusually 1 mile or 2 miles, while that of the Veeranum tank is 12 miles, and the ruined bank of the Poonairy tank, in the Trichinopoly district, is said to be 30 miles in length. Their height is generally inconsiderable, being, in many hundreds of cases, only sufficient to hold 10 feet, or even 6 feet of water. Some works, however, of this, or of the intermediate class already mentioned, are (or were) 20, 40, and even 60 feet deep. The inner side is generally revetted with stone, and has a slope sometimes of 1 to 1, but oftener of 2 to 1, or more. In some cases it is a masonry wall backed with earth. Clay puddle is not used in forming the banks, but the best earth in the immediate neighbourhood is employed, and the dimensions are made large and sometimes excessive. The height above the water-level varies; for instance, the Nundyal tank bund (Fig. 4, Plate 7) is, at one place, 18 feet high, 2 feet above the water-level, 16 feet wide on the top, with an inside slope of 1 to 1 and an outside slope of 2½ to 1. The Kolevoy (Fig. 5) tank in the Nellore district has a bank 36 feet high, 9 feet above the water-level, a top width of 12 feet, and slopes, inside and outside, of 1½ to 1.

Tanks of the 3rd, or Intermediate Class.

Of this class, the Darojee tank (Fig. 6), in the Bellary district, is a good example. The embankment is about 2 miles in length, and rests on two rocky hills, two small hillocks being also included in the line of the bank. The area, when full, is about 2¼ square miles. Its height is about 40 feet, the depth of water being 26 feet at the level of the waste-weir. This is of modern construction, and 400 feet long, the old native one having been breached. The contents of this tank are roughly estimated at 25 million cubic yards.

II. CHANNEL IRRIGATION.

As the smaller streams in Southern India are merely torrents which quickly carry off heavy falls of rain and then become dry again, their powers of supply being reckoned by hours at a time rather than by weeks or months, they are, if utilized for irrigation at all, in most cases intercepted by chains of tanks of the 2nd or 3rd class built across their course. Therefore it is only the more important rivers that can supply means of extensive irrigation by channels diverted from them, and it is believed that all of these rivers were, to some extent, laid under contribution in former times.

Naturally their deltas formed the best ground for irrigation, and, consequently, the Godavery and the Kristna deltas, and the lands in the lower parts of the course of the Pennair, Palar, Cauvery, &c., have been, to a large extent, irrigated for ages, and the works have been much extended and improved by the British Government. It is chiefly from these exceptionally favoured districts that the wonderful—and in some cases almost incredible—results of channel irrigation have been obtained. As descriptions of many of these works are accessible to the members, it seems unnecessary to occupy time in giving any account of them in this Paper, further than to say that, with one important exception, the conditions under which they were constructed are as favourable as they could be, viz., ground sloping moderately towards the sea and from the river—the source of supply, so that distribution of the water commences almost immediately; the absence of deep or hard cuttings in the canals; and, in the case of the modern improvements, the presence of a considerable population accustomed to the construction of such works and alive to the advantage of their extension. The one disadvantage referred to is the difficulty of constructing and maintaining weirs across the wide sandy beds of the rivers. This was beyond the skill of the native constructors. Very interesting accounts of some of these works will be found in the Professional Papers of the Madras Engineers, and in the Government records in the Library of the Institution.

But it is not only in the deltas that the rivers are tapped. In the middle reaches of the large rivers also there are many ancient weirs, generally admirably situated, but of rude and imperfect construction, so that many are ruined and others require extensive annual repairs. Advantage was usually taken of a reef of rocks running across the river, the low places being filled in with rubble, faced on both sides with large blocks of stone laid dry, occasionally fastened together. There is some leakage through the body of these native weirs, but not sufficient to account for the fact that, although they are not provided with scouring sluices, the bed of the river on the upper side of them has in several cases not been raised, as is the case where weirs have lately been built with scouring sluices at one end or both.

Where new weirs have been built on rock, they are generally of masonry, with a vertical or slightly battering face on the lower side. It is frequently necessary to protect the rock from the action of the falling water by a water cushion, formed by a low wall built a short way below the weir. The Author has seen a block weighing several tons picked out of what seemed, before the weir was built, a solid bed of gneiss with no visible seams; the height to the crest of the weir was, speaking from memory, not more than 7 feet, and there may have been 5 or 6 feet going over the crest. The Author knows of no rule for determining the depth of the water cushion, by the height of the fall and the volume of the water. The greatest depth of the hole formed by the water-fall in the new outlet of the Mudduk Masoor tank is 24 feet. At the low state of the river, the height of the lip of the fall is 27½ feet above the surface of the water below. In ordinary states of the river, the general depth of the cushion, or well, is to the height of the fall as 3 to 4 where the greatest action takes place, and 1 to 2 in the other places. At the Gairsoppa Falls, in the Western Ghâts, the Rajah fall, which through its whole height falls clear of the rock, is 825 feet high, and the pool into which it falls is 138 feet deep in the low state of the river. Perhaps 8 feet on the edge of the fall would be the depth in floods, and then the surface of the cauldron below, if it could be said to have one, would be raised many feet: it would be impossible to measure it. An experimental fall on the Baree Doab canal (Fig. 3, Plate 7) had a height of 6·9 feet, depth of well 9 feet, and 3·6 feet on the crest, which gives the depth of the well to the height of the fall as 3 to 4; and it is said the water had no injurious effect on the bottom of the well, and that a bottle, loaded so as to be of the same specific gravity as the water, and passed over the fall, did not reach the bottom by a foot and a half.[1] As an illustration of the force of the water, where the volume and height are both considerable, but by no means exceptional, a sketch from measurements by Major

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[1] The subject of water cushions is one which is well worthy of attention, but is too extensive to be included in this Paper.

Johnson, Assoc. Inst. C.E., is given in Fig. 2, showing the boil of the water below the Sreeramadavara dam, in Mysore.

In sandy-bedded rivers, the modern practice is to build the weir on a foundation of wells filled with concrete, to give it an apron sloping about 1 in 12 from the crest, with a toe wall, and if the slope is long, one or more intermediate walls, also built on wells and below all a broad layer of rough rubble of large dimensions. A good example of this kind is the Madras Irrigation Company's weir across the Pennair, near Cuddapah, of which a description will be given to the Institution by Mr. Higginson, M. Inst. C.E.

All the ancient irrigation channels from above weirs, that have come under the Author's notice, have far too great a fall, and consequently cannot get away from the river, and thus only a narrow strip of land is irrigated; the sides and bed of the channel get cut away in some places, and the material deposited in others, so that annual repairs and clearing out are necessary. There is also invariably a great waste of water in distribution; but as the surplus runs into the river it is not lost, being picked up again at the next weir. The tail of one channel generally overlaps the head of the next for some distance in the native system. There can be little doubt that this system of numerous weirs and small channels, with a rapid fall, is radically wrong, when applied to large rivers for extensive irrigation. On smaller rivers, having a steep fall, say of 10 feet or more per mile, rocky beds, and widths so moderate as to make the cost of the weir a small part of the whole work, it may sometimes be well applied—the more so as in such situations the soil is likely to be of a light and porous nature, requiring a large quantity of water to be spread over it, and delivering the surplus by drainage into the river again. Generally speaking, however, in the case of large rivers, it will be found more economical to take off a canal of larger dimensions from one head. The surface fall of the water can then be much less than in a channel the depth of which is small; the canal will rapidly recede from the river bank, and command, compared to its length, a much larger area of land; it will wind less, as it will cross the drainage valleys higher up, where they are less deep; these drainages will require less expensive aqueducts and approaches; there will be a shorter length of unproductive canal at the head (from the off-take to where the canal level is high enough to deliver water on to the surface of the ground); and it will supply water to lands and villages where it is more urgently needed than it is close along the banks of a river. Careful estimates, however, are needed, in each case, of considerations on the other side. For instance, the canal must not be made of so large a capacity that a great part of the water must be carried very many miles before it can be used. The cost of distribution, too, must be considered. Although the natural channels of streams can often be used to convey part of the water to the fields, it is generally the case that, for extensive irrigation, artificial channels, carried down the ridges crossed by the canal, are more economical, but they must not be too long.

It is desirable that a main canal should command a much greater area of arable land than the water it carries can irrigate constantly. Some land may not be suitable for irrigation at all; and in no case could all the land be converted from dry to wet cultivation under many years, as three times the population would be required to cultivate it. There should, therefore, be facilities for completely irrigating detached areas at considerable intervals, and for giving occasional irrigation to dry crops. This last would be an immense boon, since in many parts complete failure of the crops now grown happens every few years from drought, and a good crop is a rare exception; while from one to three waterings would insure a good crop every year. A failure of the crop means a famine; and although, in the few districts traversed by railways, food and seed grain for next year could, at a great cost, be provided for the people, fodder, and, above all, water for the cattle, could not, and they must be driven away or perish. At one large military station, so great was the scarcity of water in the early part of the year 1871, that arrangements were actually completed for carrying water a distance of 8 miles on railway-trucks for the use of the inhabitants. As to drink water thus provided would be contrary to the religious obligations of caste-men, their dismay was great. Fortunately, a heavy rain furnished a supply for two or three months.

III. Distribution of Water.

The large storage tanks already described as of the 1st class do not have more than a limited area of land irrigated immediately from them. Their duty is to store flood-water which would otherwise run to waste, and to let it down the river as it is required, to supplement, if necessary, at the end of the season, the regular monsoon supply for the first crop, or to give a supply for a second, and to be distributed either by channel irrigation from the river, or from the flat-country tanks, if it is used to supply them. From the 2nd and 3rd class of tanks the distribution is generally effected directly, beginning close under the tank, the water being let out on to the land by sluices at different levels. In some cases, however, as in that of the Darojee tank already mentioned, the water is also carried down the beds of the intercepted streams and picked up by weirs put across them at intervals; but this is the less frequent plan. One advantage of it is, that the drainage and also the superfluous water from the fields, for it is always wastefully used, are not lost.

Distribution from a canal is most economically effected when the latter runs along a ridge between two valleys, so that it can supply water on both sides; for the nearer the irrigated land lies to the supply the less do the distribution channels cost. This situation, in the case of a large canal taken from one of the main drainages of the country, can obviously happen only in rare instances. When the main canal is carried along sidelong ground crossing the drainage of the country, the main irrigating channels will generally be carried down the ridges between the streams, giving off secondary branches right and left. Occasionally, when the main canal passes by a cutting through a ridge crossing its course, a channel on a falling contour will be required on the upper, and another on the lower slope of such ridge, uniting when the crest of the ridge falls to their level. The first kind, or ridge channels, have the advantage of crossing no drainage, of being thus less liable to damage from heavy rains, and of commanding a given area with the least length of side channels. In most cases both kinds of channels will be needed. In the Ceded Districts, distribution can be carried out for 5*s.* per acre, including the sluices in the main canal bank, and all necessary works for crossing roads and streams built in a permanent manner, but excluding the cost of terracing the land to prepare it for wet cultivation,—this being done by the occupier.

Of course, any system of irrigation must include ample means of drainage. This is afforded naturally in the part of India under consideration, the fall of the country being generally steeper than is necessary. Only surface drainage is practised. For rice cultivation the water must not be carried off too rapidly, but should be retained for months at a depth of 6 inches on the surface of the ground, by surrounding the plots with a small bank, through which a slight stream is allowed to pass on and off. For dry crops the ground never holds too much rain: the more careful cultivators endeavour to retain, by small dams of dry rubble or boulders, the finer parts of the soil, which would otherwise be carried off by the very heavy rains; but, except in irrigated lands, drains are never cut, as far as the Author is aware.

IV. Value of Water to the Cultivator.

The following three statements of the cost and profits of cultivation are given from information supplied to the Author by the Deputy Collector, who made the calculations from actual experiments on fields in the Bellary district. The prices of produce are those which prevailed before the great scarcity, amounting to a famine, in 1865–6.

(*a*). Cost of Cultivating an Acre of Cholum (Sorghum), the staple dry grain.

	R.	*a.*	*p.*	*R.*	*a.*	*p.*	
Land cess	1	8	0				Average. From experiments in the village of Amrawutty; an ordinary crop.
Labour	2	6	2				
Use of cattle	5	8	7				
Manure	6	2	6				
Seed	0	9	10				
Fees to village servants	0	13	0				
Total expenses	..		..	17	0	1	
Returns.							
Grain, 236 Bellary seers, at 18 per rupee	13	1	9				
Straw, 2 loads	8	0	0				
				21	1	9	
Net profit per acre . . . . Rs.				4	1	8	
or, £				0	8	2½	

This dry crop is sometimes assisted by irrigation from wells, the water being raised by bullocks. The wells cost, in the Bellary district, from £30 to £100 each, and the cost of raising the water is said to be £4 12*s.* per acre. No well will supply more than three acres in that district. The Author has no results from actual experiment of the profits of such cultivation, but it is not probable that a greater direct profit can be made from it than from the dry cultivation. The gain is in the certainty of the crop.

To compare the above with the profit from rice cultivation, the water rate and the cost of preparing the land, or of converting it into terraced land, must be assumed. The former varies considerably, and was established when grain was much cheaper than it is now. It was the opinion of the collector of the Bellary district, in 1866, irrespective of the scarcity then prevailing, that the ryots could well afford to pay for new irrigation £1 per acre for the first crop, which is the most valuable; and the Author has been assured, both by cultivators themselves and by native revenue officials, that they would be glad to do so. The Government Superintending Engineer for Irrigation recommended for that district a rate of 17s. for the first, and 13*s*. for the second crop. The Madras Government, however, decided that 12*s*. per acre for each crop should be the standard for calculations. As a matter of fact, ryots in the Nizam's country, adjoining the Bellary district, pay as much as £3 for wet land. In the following statements the Government rate of 12*s*. is assumed. The cost of preparing the land is taken at £1 per acre, which, at 12 per cent., the usual rate of interest, gives 2*s*. 6*d*., nearly, per acre per annum. (See Tables *b* and *c*, next page.)

The difference between this and two dry crops, supposing two could be got, is £17 10*s*. in favour of the wet crop.

Sugar-cane, however, as well as garden cultivation, which is also extremely profitable, would generally bear only a small proportion of the breadth of land that would be under rice and dry crops, and in the following Table I. (p. 388), showing the comparative yield of wet and dry crops, they are neglected.

As the Bellary district is peculiarly unfortunate in its annual rainfall, the above valuation of an average dry crop may be under the average of that in the districts which could be supplied with channel irrigation; and in the following Table, the average yield per acre in the Kurnool district and the prices there prevailing, which are lower than in Bellary, both of wet and dry crops, have been used for the purpose of comparison between wet and dry cultivation. It should be noted, however, that land irrigated from a river gives a better return than that under a tank by, it is said, 25 per cent. in those parts. Whether this is principally due to the brackish quality of the water locally collected, or to the insufficient supply from tanks, the Author cannot say; probably both causes contribute.

The following Table is intended to show the money value of irrigation, and the gross returns per acre which would be got by the construction of suitable works in the Ceded Districts, and in others similar to them in climate and other circumstances. Nos. I. and IV. are compiled from official statements of the average value of crops in the five years 1861 to 1865 in the Kurnool district. Nos. II., V., and VI. from actual experiments by the Deputy Collector in the Bellary district. No. III., col. 4, from the same source, and cols. 1, 5, and the rest from official statements in the revenue department. The price of grain is steadily increasing, when taken over a number of years; thus the price of rice in the Table, 1861-65, is double what it was in the disastrous famine year of 1854, and 78 per cent. higher than the average of the period (*b*). COST of CULTIVATING an ACRE of RICE.

	R.	a.	p.	R. a. p.
Land cess	1	8	0	For good land.
Terracing land	1	4	0	Assumed Government proposal.
Water rate	6	0	0	
Labour	18	15	0	From experiments in the village of Chitwady.
Use of cattle and implements	11	0	0	
Seed	9	8	0	
Manure	2	10	0	
Village fees, &c.	3	12	0	
Total cost of cultivation	..	..		54 9 0
RETURNS.				
Paddy, 1,675 Bellary seers, at 18 per rupee	93	0	0	
Straw, 40 bundles	10	0	0	
				103 0 0
Net profit per acre . . . Rs.				48 7 0
or, £				4 16 10½

Or a difference in favour of wet cultivation of £4 8*s.* 8*d.* per crop per acre.

(*c*). COST of the CULTIVATION of an ACRE of SUGAR-CANE, which requires the same quantity of water as an Acre of Rice, but spread over ten months, and thus liable to the double water rate, or Rs. 12.

	R.	a.	p.	R. a. p.
Land cess	1	8	0	
Terracing land	1	4	0	Assumed Government proposal.
Water rate	12	0	0	
Labour	232	0	0	From the Deputy Collector's experiments in Chitwady.
Use of cattle, &c.	10	0	0	
Manure	50	0	0	
Plants, 6,000, at rupees 5 per thousand	30	0	0	
Fuel, 48 loads	48	0	0	
Village fees, &c.	8	0	0	
Total cost of cultivation	..	..		392 12 0
RETURNS.				
288 maunds of jagherry, at rupees 2 per maund	..	..		576 0 0
Net profit per acre . . . Rs.				183 4 0
or, £				18 6 6

TABLE I.

SHOWING the Compar

	DESCRIPTION OF CROP.	1. Gross Value.			2. Deduction for Risk.			3. Gross Value for Assessment.		
		R.	*a.*	*p.*	*R.*	*a.*	*p.*	*R.*	*a.*	*p.*
	DRY CROPS.									
I.	Grain, 243 Madras measures, at per Garce Rs. 278	21	1	9		¼				
	Straw, 50 bundles, at 4 annas	12	8	0						
	Revenue returns, 5 years' average	33	9	9	8	6	5	25	3	4
II.	Grain, 236 Bellary measures, at 18 per rupee	13	1	9						
	Straw, 2 loads, at Rs. 14	8	0	0						
	Deputy Collector's experiment	21	1	9	..	..		..	..	
III.	The same, with occasional Irrigation. Grain, 333 Madras measures, at per Garce Rs. 278	28	15	0		⅙				
	Straw	20	0	0						
	Collector's official statement	48	15	0	8	2	6	40	12	6
	WET CROPS—RICE.									
IV.	Grain, 1,066, at per Garce Rs. 213	70	15	3		⅙				
	Straw	12	8	0						
	Revenue returns, 5 years' average	83	7	3	13	14	6	69	8	9
V.	Grain, 1,675 Bellary measures, at 18 per rupee	93	0	0		⅙				
	Straw	10	0	0						
	Deputy Collector's experiment	103	0	0	17	2	8	85	13	4
VI.	SUGAR-CANE.					⅙				
	288 maunds jagherry, at Rs. 2	576	0	0	96	0	0	480	0	0

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* Col. 4. For details of cost, furnished by the Deputy Collector, see Sect. IV. *ante*.

† Col. 5. From the amounts in Col. 5, a sum of R. 1 2a. land rent, has to be de show the clear profit to the cultivator. The rent has been deducted in Col. 11.

TABLE I.

-and DRY CROPS.

	6.	7.	8.	9.	10.	11.	
ie).	Second Crop at Three-quarters First Crop.	Value of Water.	Sum of Cols. 5 & 6.	Assessment at Half Net Produce.	Profits of Water to Cultivator One-third.	Profits of Water to Works Two-thirds.	
p.	R. a. p.	R. a. p.	R. a. p.	R. a. p.	R. a. p.	R. a. p.	
3	.. ..	.. ..	.. ..	4 13 6			
8	.. ..	.. ..	.. ..	2 12 6			
) 6	.. ..	15 5 3	.. ..	12 8 3	5 1 9	9 2 6	
7 9	16 13 7	12 12 6 29 10 1	39 5 4	11 4 0 19 8 0	4 4 2 9 14 0	7 6 4 18 10 0	1 crop. 2 ,,
12 4	29 1 3	29 1 1 58 2 4	67 13 7	19 0 0 34 0 0	9 11 0 19 6 1	17 14 0 37 10 2	1 crop. 2 ,,
‡ 12 0	.. ..	81 5 6	100 12 0	50 0 0	27 2 0	52 12 0	10 months' supply.

Col. 5. It is generally reckoned in the Ceded Districts, that the profits per acre of sugar-cane
Rs 200, or a little more than those given in the Table, without the deduction for risk in
4.

TABLE I.

SHOWING the COMPAR

Description of Crop.	1. Gross Value			2. Deduction for Risk.			3. Gross Value for Assessment		
	R.	a.	p.	R.	a.	p.	R.	a.	p.
Dry Crops.									
1. [illegible] Madras measures at per Garce [illegible]	21	1	9	¼					
[illegible] at 4 annas	12	8	0						
[illegible] 5 years' average	33	9	9	8	6	5	25	3	4
2. [illegible] Bellary measures at 18 per [illegible]	13	1	9						
[illegible] at Rs 14	8	0	0						
[illegible] experiment	21	1	9	..	..		..	..	
3. [illegible] Irrigation. [illegible] measures at per Garce [illegible]	28	15	0	¼					
[illegible]	20	0	0						
[illegible]	48	15	0	8	2	6	40	12	6
Wet Crops—Rice.									
[illegible] Rs 213				¼					

Table I.

and Dry Crops.

ue p.	6. Second Crop at Three-quarters First Crop.	7. Value of Water.	8. Sum of Cols. 5 & 6.	9. Assessment at Half Net Produce.	10. Profits of Water to Cultivator One-third.	11. Profits of Water to Works Two-thirds.	
p.	R. a. p.	R. a. p.	R. a. p.	R. a. p.	R. a. p.	R. a. p.	
3	.. ..	.. ..	.. ..	4 13 6			
8	.. ..	.. ..	.. ..	2 12 6			
0 6	.. ..	15 5 3	.. ..	12 8 3	5 1 9	9 2 6	
	16 13 7	12 12 6 29 10 1	39 5 4	11 4 0 19 8 0	4 4 2 9 14 0	7 6 4 18 10 0	1 crop. 2 ,,
				0 0 0	9 11 0 19 6 1	17 14 0 37 10 2	1 crop. 2 ,,
					7 2 0	52 12 0	10 months' supply.

profits per acre of sugar-cane
t the deduction for risk in

4.

1856-60. The Author believes that the new settlement rates of assessment of land are about one half the clear net value of the crop, after a deduction for risk of loss by bad seasons, &c., has been made from the gross returns, of ¼th for dry and ⅛th for wet crops; and column 9 in the Table has been made in accordance with this principle. It is probable that, in addition to the direct increased value of the crops, some further advantage would have to be given to the ryots, to induce them to convert their land from dry to wet cultivation, in districts where wet cultivation is but little known; and supposing the total advantage to be divided in the proportion of one part to the cultivator and two parts to the agency or works supplying the irrigation, the results are given in cols. 10 and 11. The sum of R. 1 2*a*., to represent the average land cess already paid by the ryot to the Government, has been deducted in col. 11; it is not included in col. 4 because, to show the value of water applied to land already paying that dry rate, it is necessary to exclude it from all the items in col. 5, and it is assumed that this rent of the land is not raised, but only a charge is made for the water. As No. V. represents good land, it would, perhaps, be too much to assume that in average cases the out-turn would be as high as is entered in col. 8 of No. V. On the other hand, No. IV. is the result of tank irrigation; and the results ought, in dealing with river irrigation, to be increased 25 per cent. But even excluding No. V., and taking No. IV. as it stands, and excluding also No. VI., on account of the comparatively small area sugar-cane would occupy, the results of Nos. III. and IV. show that, provided a water-rate proportioned to the value of the water were fixed, irrigation would, even taking the most unfavourable cases, benefit the cultivator to the extent of 10*s*. and 8*s*. 6*d*., and yield a gross return to the works of 18*s*. 3*d*. and 14*s*. 9*d*. per acre respectively in the two cases of occasional watering of dry crops and of rice or wet cultivation; and in the latter case, supposing water to be stored for a second crop, the gain to the cultivator would be 19*s*. 9*d*., and the return to the works 37*s*. 3*d*., which cannot be considered as other than very favourable terms to the former, who is not to be supposed to have expended any capital on the improvements beyond 1 rupee per acre for the conversion of the land, and this has been allowed for. As 18*s*. 3*d*. and 14*s*. 9*d*., or the average of them, 16*s*. 6*d*., represents the gross income from the sum expended on the construction of the canal and distribution channels, so (37*s*. 3*d*.—14*s*. 9*d*.) 22*s*. 6*d*. represents the gross additional return per acre from storage water applied to a system of works already constructed.

V. Cost of Works.

First, of canals as they are needed either to distribute water directly or to fill existing tanks. It has been laid down by the Madras Government, as a basis for calculation, founded on experiments made by their orders, that 2 cubic yards per hour, or 0·015 cubic foot per second, in the main canal is sufficient for the irrigation of an acre of paddy. Where more is used in porous soils, the surplus will, in a good system of distribution, be caught up again in the drainages and redistributed. For dry crops three waterings in the season, of 4 inches in depth, in years when the rainfall is at the lowest, and 2 inches, or 1 inch, in less unfavourable years, would suffice to insure a good crop of cholum. The first quantity is equal to 1 cubic yard per hour per acre, nearly. It is convenient, for the sake of comparison, to reckon the cost of a canal in terms of its carrying capacity at the head; and if the above allowance of water be assumed, the cost can readily be compared with the returns per acre. Table II. gives the cost of several works which have been constructed, or carefully estimated on data obtained from constructed works, in the Ceded Districts:

Table II.

Name of Work.	Cost per Cubic Foot per Second at Head.			Cost per Acre.			Number of Acres Irrigated.
	£	s.	d.	£	s.	d.	
Kurnool Canal, for irrigation and navigation	533	6	0	8	0	0	200,000
Bellary high level	439	0	0	7	6	2	150,000
Bellary low level	393	6	0	5	18	0	212,500
Toombaganoor Canal	526	14	0	7	18	0	55,000
Average	473	1	6	7	5	6	154,250

It is to be remarked that the Kurnool canal is also a navigable canal, which raises its cost considerably; probably $\frac{1}{5}$th may be deducted to reduce it to its cost for irrigation only, that being the proportionate amount of cost found by estimates to be necessary to make other irrigation canals navigable. It would then cost per cubic foot per section, £426 12*s.*, and per acre, £6 8*s.*; and the average would be reduced to £446 8*s.* per cubic foot per second, and £6 17*s.* 8*d.* per acre. The following is the cost, ascertained or estimated, of large canals in other parts of India:

TABLE III.

NAME OF WORK.	Cost per Cubic Foot per Second at Head.			Cost per Acre.[1]			Authority.
	£	s.	d.	£	s.	d.	
Ganges Canal with navigation	497	12	0	7	8	9	Roorkee pamphlet.
Ganges Canal without navigation, assumed .	398	1	7	5	18	5	⅕th deducted.
Baree Doab Canal . .	466	12	0	7	0	0	Capt. Forbes, R.E.
Sutlej Canal	353	6	0	5	6	0	Capt. Crofton, R.E.
Soane Canal	434	8	0	6	10	0	Col. Dickens, R.E.
Average . . .	413	2	0	6	3	7	
The Orissa system . .	200	0	0	3	0	0	Col. Rundall, R.E.

The Orissa system of canals is not included in the average, as the works are in a deltaic country. The low rate of cost bears out what has been already stated. It seems safe to assume, that canals large enough to irrigate 75,000 acres and upwards can, on an average, be constructed for £7 per acre, and that, with the distribution of profits before proposed, the outlay of £7 will yield a gross return of 16*s.* 6*d.* Deducting 2½ per cent. on the cost of construction for establishment, repairs, and collection of revenue = 3*s.* 6*d.* per acre, the net returns ought to be, at rates extremely favourable to the cultivator, 13*s.* per acre. The works, according to their magnitude, would occupy a good many years in construction; and although partial irrigation might take place after the head-works and one-half of the other works were constructed, still the whole profits could not be realized till some years after the works were complete. If 5 per cent. on one half the capital for ten years be added to the cost, it is brought to £8 15*s.* per acre, and the net profits would then be 7·4 per cent. This applies to channel irrigation only, where all the works have to be constructed; the profits would be greater were there tanks along the line of the canal and at its terminus which could receive a partial supply, for a second crop, or for flooding dry crops, during the time when the water was not required to be turned on to all the fields.

Secondly. In considering the cost of tanks, it is to be remembered that those of the 1st class, or storage reservoirs, would rarely be available for direct distribution, and would rather be considered as subsidiary to a system of works already constructed. The flat-country tanks, on the other hand, affording as they do means of directly distributing the monsoon supply, may be compared as a means of irrigation with the head-works and channels from a river. Those of the intermediate class add, in some cases, to the functions of the last mentioned, that of storing a certain amount of water for a second crop of rice, or of other grains which require a supply of water in the dry season. Taking the flat-country tanks first: it can well be believed that the old ones, constructed as they, no doubt, chiefly were by the voluntary, or sometimes forced, labour of the villagers whose lands they were to benefit, have, in the course of centuries, amply repaid the labour expended on them; but it would only be under exceptionally favourable circumstances, such as have never come within the Author's personal observation, that their construction would be a profitable investment for capitalists now. This is in a great measure owing to the loss by evaporation in shallow tanks. If the main slope of the country be assumed at as little as 8 feet per mile, and the lateral slope towards the stream to be closed at 10 feet per mile, then a rough calculation will give the contents of a tank whose greatest depth of water is 9 feet at about 3 million cubic yards; and, taking the evaporation[1] at 42 inches in four months on the mean area, it amounts to 2·18 million cubic yards, leaving only 820,000 cubic yards for irrigation, or sufficient for 205 acres. The cost of the work would be:

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[1] Of rice land at the Madras rate, 2 cubic yards per hour per acre.

		R. a. p.	Rs.
Earthwork	C. Y. 52,792 at	0 2 0	6,600
Stone pitching	,, 4,200 ,,	0 8 0	2,100
Waste-weir and sluices . . .	..	..	2,000
Distribution to 205 acres . . .	.. ,,	2 8 0	512
Contingencies, &c., 15 per cent. .	..	..	1,588
Total	..	Rs.	12,800

Or about £6 5*s.* per acre for an extremely favourable imaginary case, where it must also be assumed that the minimum rainfall would suffice to fill the tank. An actual example of this kind of tank, which intercepted the water of three streams and included cuttings to connect them, was estimated by the Author to cost £15,000 for 3 million cubic yards of available water, or about £25 per acre. As another example, both of the varying cost of flat country tanks and of the value of water to a cultivator, the Author is acquainted with the following illustration. Chinnaveerappa, a wealthy landowner, had expended £2,500 on a tank, which was still unfinished, and would eventually cost at least £3,000, and be equal to the supply of about 240 acres. Adding the cost of distribution, this would be at least £14 per acre; and the man said it would pay him well. And there is no doubt of it; for the land would raise sugar-cane, and he would reap both the cultivator's and the capitalist's profit.

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[1] One-third of an inch per day is the observed evaporation in the plains.

Although the construction of new works of this kind must be considered a doubtful investment, there are many cases where a small outlay in repairing breached banks, and in supplementing the water supply by digging catch-water drains, or diverting neighbouring streams into a tank, or even by the construction of feeders of considerable length from well-supplied rivers, would be speedily repaid; but without regular surveys it would be impossible to guess even at the number and capacity of tanks that might be thus restored. Many have so silted up that they are best left as they are. This silting up, and the consequent abandonment of flat-country tanks, though a matter of time, is also one of certainty.

The intermediate class of tanks show a better result, as might be expected from their greater depth (as a rule), and consequently less loss by evaporation. The Sholapore tank was estimated by Col. Fife, R.E., to cost about £100,000, which at Madras rates for rice would be £11 per acre. The loss by evaporation was estimated at 29 per cent.; the depth at the dam being 60 feet. This rate of £11 per acre for rice cultivation is stated for the sake of comparison; but rice is not the chief grain irrigated under it, and the net return of the tank was estimated to be 9 per cent. at the low rates of Rs. 4 for a four-months' crop. The Bourg reservoir in Ganjam, constructed by the Madras Government at a cost of £1,075, waters an area of 1,632 acres, and yields an increase on the old revenue of the land of £184 10*s*., or, deducting repairs, 16½ per cent.

The storage reservoirs of the first class which have been designed and estimated show a very different result from that given by the other classes. The Author is informed that the result of the investigations of the Bombay Engineers is that, in favourable cases, 700 cubic yards of water can be stored per rupee, which nearly agrees with his own estimates in detail of several reservoirs, one of which would store 750, another 425 cubic yards; while the restoration of the Mudduk Masoor tank previously described would yield 960 cubic yards per rupee. The evaporation, calculated from observations, is 7½ per cent. in the two proposed new reservoirs in seven months, and 5 per cent. in the Masoor reservoir if emptied in four months. A further deduction has to be made for evaporation in the course of conveyance to the fields to be irrigated, which will vary with each case. In these cases it will be 2⅓ and 8 per cent. Assuming the correction for evaporation to be 12 per cent., and the allowance of water per acre at 5,000 cubic yards per acre, which is a little in excess of 2 cubic yards per hour, and adding, as in the case of the channels, 25 per cent. for interest during construction, the rate of storage becomes, for the proposed new reservoirs, 440; the Bombay rate, 493, and the Masoor reservoir, 674 cubic yards per rupee; and the cost per acre, £1 2*s.* 6*d.*, £1, and 14*s.* respectively. Such storage reservoirs, when built on main rivers rising in the Ghâts, would have a supply that could always be reckoned on; and on the larger rivers the difficulty would be, not the filling of any reservoir, but the construction of one large enough to intercept a large portion of the floods of one season, or failing that, the disposal of the surplus water. As an example of this: in one of the proposed reservoirs just referred to, which had a depth of 160 feet at the dam (about the same as that built in the Gouffre d'Enfer in France), the water toward the upper end of the lake would overtop the summit of the water-shed of the river Toonga and the Gurget, a river flowing to the western sea; and yet the quantity of water contained by the reservoir would only be about ¾ths of the ordinary monsoon supply. The above sites for reservoirs were selected as likely to be very favourable, the capacities of two of them being also very great; and therefore the rates are probably cheaper than the average at which water could be stored in rivers having a certain supply, and undoubtedly so as compared with those on rivers with a much more fluctuating supply. Taking the least favourable of these sites, however, 340 cubic yards per rupee, there is still only a prime cost, after all deductions, of £1 12*s.* 9*d.* per acre for giving a second crop of rice, or a crop of sugar-cane. The cost of establishment and maintenance on a masonry dam would not be great, and may safely be put at 2 per cent., or 7*d.* per acre, or even less. The additional maintenance of the channels would not exceed 1*s.* per acre; so that it will appear that an outlay of £1 12*s.* 9*d.* will return about £1 1*s.* This allows a large margin for the profitable construction of reservoirs on rivers having a less certain or regular supply.

The following estimates of Government works are examples of the profits to be made by repairing, improving, or adding to works already in existence. In one instance, that of the Trivady Anicut in South Arcot, an expenditure on repairs of £1,100 or £1,200 produced a revenue of £3,000, or 250 per cent.[1]

TABLE IV.

Name of Work or Project.	Nature of Works to be Constructed.	Cost per Acre.			Net Returns at Rs. 6 per Acre.
		£	s.	d.	
Tambrapoorney .	Weir and channels, and enlargement of old ditto.	2	12	0	16¼
Kanagiri, in Nellore	Head works and channel to a tank which is to be enlarged.	3	2	0	Not stated. ? 17
Muddoor, in Mysore	Weir and channels to old tanks	Not stated.			45
Sreeramadavara, Mysore.	Ditto ditto ditto	2	3	1	27
Bhatodee, Bombay Presidency.	Restoration of old tank and channels.	6	0	0	10

VI. GENERAL CONCLUSIONS.

As there seems to exist a general impression, that the estimates of the benefits of irrigation are merely estimates, more or less coloured by personal views, the Author has, in the statements of the comparative results of wet and dry cultivation, confined himself to ascertained facts, and has endeavoured to keep the estimates of returns on works within the limits of certainty, by excluding all doubtful or unascertainable profits, such as those from plantations for firewood (a very profitable investment where the earth can be kept sufficiently moist) water supplied to towns and villages for domestic and municipal purposes, water-power, &c. Also, he has taken as the standard of productiveness that of irrigation under tanks, and has not added the 25 per cent. additional crop said to be due to channel irrigation.

As this Paper is intended to deal with works for irrigation only, navigation is not included in either the cost or the returns; but the Author begs leave to make one or two remarks on this subject, on which so much opposition exists in the views of Engineers. This opposition he believes arises from each side attempting to form general conclusions, and to lay down a general rule founded on the observation of particular works, which in each case seem to bear out its advocate's views. The question does not admit of a general answer, either in favour of or adverse to the combination of irrigation and of navigation in one channel. Assuming that a navigable canal is desirable, if it can be constructed at a small outlay, the question whether an irrigation canal should be adapted to that use or not seems to depend for its solution mainly on two circumstances: first, the nature of the ground through which it passes, and, secondly, on its dimensions. If the former is such that a rapid current can be given to the water, it is very desirable to do so in cuttings, in order to reduce their cross section, and this generally to such an extent as would prevent upward navigation. If, on the other hand, the country is very level, as in deltas, and the soil so light that the velocity of the canal has to be small, then the addition of works required for navigation bears so small a proportion to the whole outlay, that to make the irrigation canal navigable is the cheapest way of attaining the end. Thus, in the Orissa scheme, the cost of the navigation works is said to be about one-eighth of the whole cost; and a complete network of navigable lines is obtained at an outlay of £650 per mile. In a less easy country the Author has found that when a canal has to carry from 150,000 to 500,000 cubic yards per hour, and when it has to pass through cuttings, it would be cheaper to have a separate navigation taken round, or in some other way avoiding the difficult parts, than so to enlarge the irrigation canal as to reduce its current within navigable limits. But when a canal has tapered down to 150,000 or 100,000 cubic yards per hour, then it is cheaper to combine irrigation with navigation in one canal. In a tract of country comprising both characters of ground, it was found that to combine a system of navigation with irrigation would add 25 per cent. to the cost of the latter, and would cost from £2,000 to £3,000 per mile, according to the dimensions of the work; but in difficult ground, if the canal were of large dimensions, carrying 450,000 cubic yards per hour, £6,000 per mile would be required to make it navigable. The parts of the canal used for navigation only would cost £1,200 or £1,500 per mile, exclusive of the locks, which, if 100 feet long and 20 feet wide, would cost about £200 per foot of lift. These rates per mile suppose a supply derived from the canal, and do not include headworks or storage reservoirs, as these works are supposed to be charged to irrigation, inasmuch as the water used for lockage would also be expended in the fields.

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[1] On the authority of the late Col. J. C. Anderson.

In the above estimates no account has been taken of the value of the land occupied by the works. It has generally a low value in such districts as require irrigation.[1] In the Orissa system of works it cost 1·8 per cent. of the capital expended; and in any case it becomes quite insignificant, when compared with the indirect advantages accruing to Government from the improvement of the country by irrigation. The most obvious of these is the saving of remissions of land revenue, which have often to be made in consequence of partial or total failure of crops. There is also the relief from uncertainty in the amount of the revenue. In the irrigated districts of Tanjore, the fluctuations in the revenue have declined since the construction of the Government irrigation works from 52 per cent. to 3 or 4 per cent.[1] Other sources of gain to the State are—waste lands brought under cultivation, and so under a charge for rent; increase of the customs and taxation in general; and a large saving of money relief in times of famine. These gains cannot be estimated, and no account has been taken of them in the above calculations, except as a set-off against the value of the land.

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[1] Colonel Rundall's Report.

No special notice has been taken in this Paper of the great and very remunerative works in the Kristna, Godavery, and Tanjore deltas, the works in the last yielding, according to an independent authority,[2] after deducting repairs and 5 per cent. on the capital, 23½ per cent. direct profits, and those on the Godavery from 50 to 60 per cent. They are omitted because these deltas are so occupied as to offer no opportunity of constructing new works on a large scale.

Table V. shows how the 12*s.* rate for water, fixed by Government a few years ago as the basis of all calculations for new works in the Ceded Districts, alters the aspect of matters regarding the profits of the cultivator and the supplier of water from that given' by the "equitable" or "mutual benefit" rate adopted in Table I. The Author believes Table V. to be nearly correct, although, for reasons already mentioned, the returns may be a little understated.

Persons unacquainted with the native character will be apt to ask why, if irrigation works are so profitable, the natives have not already utilized every drop of available water; but this will be no ground of wonder to those who know their ignorance of the practice of any but their own neighbourhood, their worship of custom, and their habit of relying on their rulers to do everything for them. In the Godavery districts, on the completion of the works, the Government officers are said to have acted in a paternal manner to the ryots by turning the water on to their fields, with or without their consent, and they have been rewarded by the unexampled prosperity of the district.

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[1] Colonel Baird Smith.

[2] Colonel Baird Smith.

TABLE V.

Kind of Works to be Constructed.	Cost of Works per Acre.			Water Rate.		Cultivator's Profit per Acre.			Net Return on Works per Acre.			Per Cent. of Capital.
	£	s.	d.	s.	d.	£	s.	d.	£	s.	d.	
1. Irrigation by channels for one crop of rice .	8	15	0	14	10	1	8	0	0	11	3	6·7
	..		..	12	0	1	10	10	0	8	5	4·3
2. Ditto ditto for occasional irrigation of dry crops	3	2	0	18	4	1	9	6	0	14	10	23·9
	..		..	6	0	2	1	10	0	2	6	4·0
3. Mean of 1 and 2, supposing equal areas irrigated, and three waterings to dry crops . .	5	18	6	16	7	1	8	9	0	13	0	11·0
	..		..	9	0	1	16	4	0	5	6	4·6
4. No. 2 with one watering, and the water provided for the other two wasted or not used	3	2	0	6	0	2	1	10	0	2	6	4·0
	..		..	2	0	2	5	10	0	1	6	Loss.
5. Mean of Nos. 1 and 4 .	5	18	6	10	5	1	14	11	0	6	10½	5·8
	..		..	7	0	1	18	4	0	3	6	3·0
6. Application of storage water to existing works, giving a second crop of rice	1	9	5	22	6	0	9	0	1	1	0	71·0
	..		..	12	0	0	19	5	0	10	6	36·0
7. Combined storage and distribution works; two crops of rice . .	10	4	5	37	3	1	19	2	1	13	9	16·5
	..		..	24	0	2	12	5	1	0	6	10·0
8. Ditto ditto, sugar-cane .	10	4	5	105	6	4	13	0	5	2	9	50·0
	..		..	24	0	8	15	3	1	1	3	10·0

The first rate in each case is taken from Col. 2, in Table I.; the second is the Government rate, and in Nos. 2 and 4 the rate allowed to the Madras Irrigation Company.

The object of this Paper will have been attained if it has shown:

First. That all works of irrigation benefit the cultivator to such an extent as will enable him to pay a water-rate equal to two-thirds of the increased value of his crop, and not exceeding one-half the net value, and still to leave his own profits by 100 to 400 per cent.[1] in excess of those derived from dry cultivation.

Secondly. That of the three kinds of works mentioned in Table V., under 1, 6, and 7, the storage of water for the raising of a second crop, under distribution works already in existence, is the most profitable, and would, after paying one-third of the gross revenue to the existing works, still yield a net return of 46 per cent. on the outlay, and increase the revenue of the existing works, supposing them to have cost the average sum, by 4¼ per cent.

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[1] In sugar-cane cultivation 950 per cent.

Thirdly. That the arbitrary rate of 12*s*. per acre is insufficient, on the data assumed by the Government, to yield a fair return directly on the average of new irrigation works, unless these include the storage of water, when the Government rate will yield a net profit, on storage and distribution works combined, of 10 per cent.

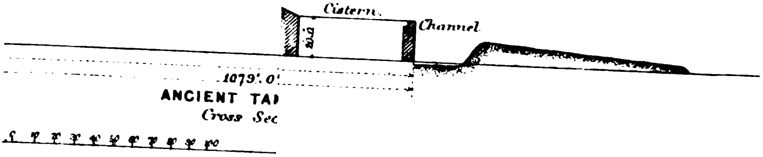
And Fourthly. That as a consequence of the last, the profitable employment of unguaranteed capital in irrigation works depends chiefly on the recognition of the principle, that the water-rate should be fixed with reference to the value of the crop produced. This value will, in all probability, continue to increase, as will also the cost of the works as wages increase; and unless the water-rate is fixed with due regard to the value of the water to the consumers, and to the cost of work in each district, many beneficial projects will remain unexecuted.

The communication is accompanied by a series of diagrams, from which Plate 7 has been compiled.

[Mr. J. H. Latham.

STOR

PLATE 7.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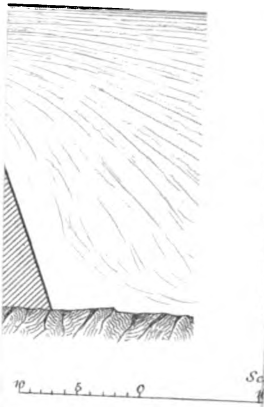

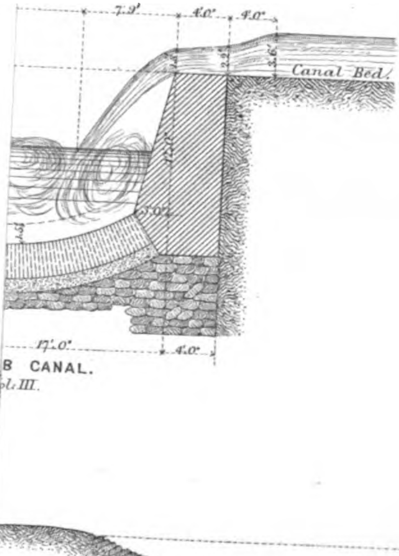
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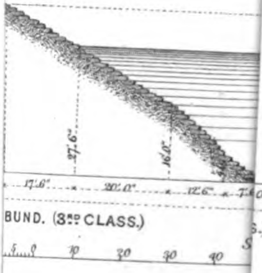
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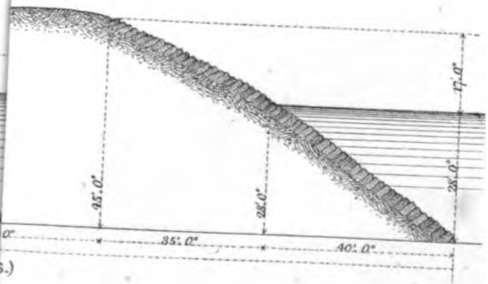
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[MR. J. H. LATHAM.

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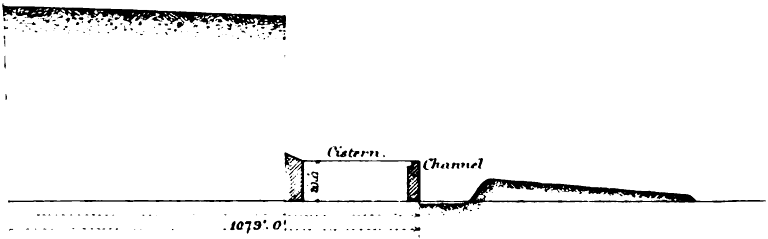
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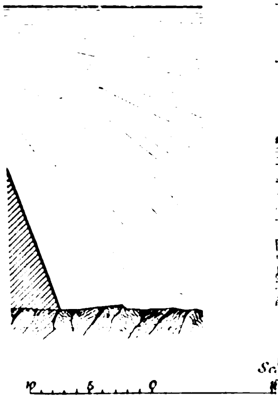

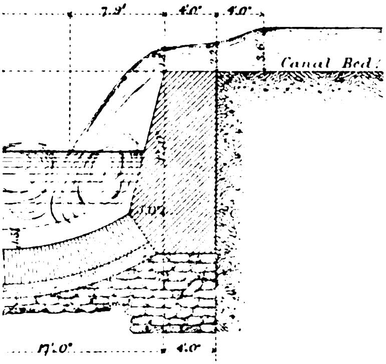
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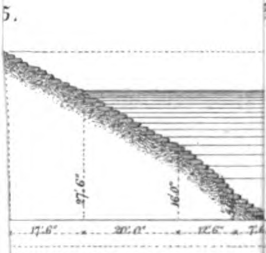
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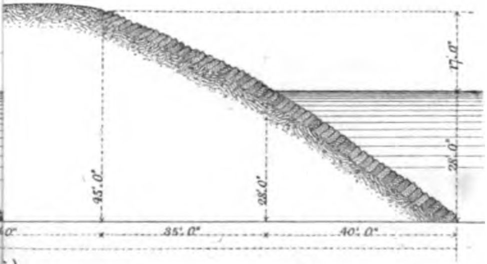
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KELL. BROS LITHRS CASTLE ST HOLBORN.

Mr. J. H. **Latham** said that his personal experience of the district in India embraced by Mr. Gordon's Paper enabled him generally to corroborate the facts stated. The old Hindoo system of village tanks must gradually come to an end, owing to the natural and inevitable silting up of their shallow beds, unless fresh tanks were continually added, as of old, to supply the place of such as became inefficient for irrigation from this cause. Mr. Latham quoted Col. Playfair, R.E.,[1] to show that, in the Deccan and South Mahratta country, the same difficulty existed in the way of this renewal as existed in the Madras Presidency, viz., that village tanks, as a rule, were not paying works. On this account a Government could not fairly spend public money upon them, for the benefit of the local villages, nor would private speculators build them. As a fact, charitable persons did not any longer come forward to build them. The old system of village tank irrigation was therefore dwindling away, and any useful system meant to replace it must involve, to a certain extent, novelty. The Madras Government seemed especially to have appreciated this, and had proved the most speculative and successful of the Indian Governments. Permanent irrigation had been secured on the coast by their well-known works at the heads of the river deltas, of which the most important on the Cauvery, Kristna, and Godavery were calculated to pay from 23 per cent. to 60 per cent.; and by the purchase of the Orissa works from a private company, which were calculated to pay this year 12 per cent. Again, in the Neilgherry hills, there seemed to be no reason why their bold attempt to construct a tank 140 feet deep by the silting process should not ultimately prove successful. But these plans were not applicable for up-country irrigation, for which the system most advocated, amongst others by Mr. Gordon and Col. Playfair, was that of river channels, combined with reservoirs for storing the water from the monsoon rains. Since the commercial success of such schemes was of primary importance, any information bearing on the actual cost of the works, or on the commercial value of water provided by them, would be interesting. A most important matter affecting the cost of the works was the provision of an adequate escape for surplus water, the quantity of which was, in some schemes now proposed, very large, necessarily delivered at a great height, and requiring costly works. Adopting the formula

$$D = C n^{\frac{2}{3}},$$

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[1] "Report on Irrigation in the Deccan and South Mahratta Country." Bombay, 20th April, 1866.

where D was the quantity of water for which escape was required for a drainage from n square miles of country, and C some constant; then, taking D in cubic yards per hour, in the designs for the Ekrooka tank, near Sholapoor, under construction by the Bombay Government,

$$D = 61{,}523\, n^{\frac{2}{3}}.$$

On the Ganges and Godavery works it was stated that escape would be provided for

$$D = 75{,}000\, n^{\frac{2}{3}};$$

and on the Madras Irrigation and Canal Company's works Mr. Latham was providing escape sufficient for

$$D = 100{,}000\, n^{\frac{2}{3}}.$$

These differences showed how important it still was to have more information on the subject.

The value of the water stored depended primarily upon the area of irrigated crop for which a given quantity of water sufficed. About this great differences also existed. The supply of each cubic yard of water per hour was taken in the Ekrooka scheme to suffice for $\frac{9}{10}$ of an acre for a year's irrigation, and for $1\frac{1}{8}$ acre for crops grown during the wet months. In the Lakh project on the Paihra, as sufficient for $\frac{3}{4}$ acre and $\frac{8}{9}$ acre, respectively, for these crops; and by the Madras Government, as sufficient for $\frac{1}{2}$ an acre only of either crop. The experience of irrigation on the Soonkêsala canal of the Madras Irrigation and Canal Company was too brief to give a definite result, but indicated that, where due care was used to prevent waste, the Bombay practice was nearer the truth than the Madras. That the Madras estimate was too low seemed also indicated by Col. Baird Smith's estimate, that a cubic yard an hour sufficed for $1\frac{1}{3}$ acre of irrigation in India. The water-rate to be charged per acre would, of course, be different for different districts, and was a mere question of the value of produce in the locality. Perhaps Mr. Gordon could give more definite information on the subject of escapes, and on the irrigating power of water in India.

Since the amount of drainage water to be provided for in these reservoirs affected their cost seriously, he would give a few particulars of the rainfall in Southern India during the time he was there. Excepting an extraordinary fall, to which he would refer presently, the greatest depth registered at Kurnool in any one month in the ten years, 1862–71, was 13·77 inches, in September, 1862; the greatest depth in one day being 4 inches, on the night of the 24th of that month. The only other occasions on which a total depth of 7 inches fell in a month were in August, 1865, 7·73 inches; and in August, 1868, 7·35 inches. Since January, 1868, when the Kurnool Observatory was established, a depth of rain exceeding 2 inches in twenty-four hours was registered on three occasions, in no case reaching 3 inches. But on the exceptional night of the 6th of August, 1870, an extraordinary storm from the south-west occurred, and 12·01 inches of rain fell in twelve hours. At a distance of 13 miles west of Kurnool, the storm was felt in the daytime of the 7th, after rain had almost ceased at Kurnool, and only 7·22 inches fell. At a distance of 30 miles east of Kurnool, an unusually heavy rain occurred during the night of the 6th. This proved that ten years' experience of one place was quite inadequate to determine the frequency of such excessive falls. Two other storms deserved notice; one at Gooty, and the other at Tâdamurri, adjacent talooks in the Bellary District, in the autumn of 1864, when a depth of above 8 inches of rain fell in one night. The other was a short storm, which he gauged, at Böanassey, on the 72nd mile of the canal, when for thirteen minutes rain fell at the rate of $3\frac{3}{4}$ inches an hour.

The interests of the Canal Company had hitherto required that water should be given to the village cultivators in excess of what they used for cultivation. As to observing an experimental patch of ground, there were insuperable difficulties in the way; for if the patch were isolated the water percolated through the soil and irrigated the surface for yards around, besides passing away through the subsoil. On the other hand, if the patch were surrounded by wet cultivation, the result could not be trusted, so easy was it to transfer water from one field to another surreptitiously; and if the result were trustworthy it would not give the average requirements for cultivation. The only proper observation would be to see how much water per hour per acre was actually used—when it was served out without waste; and that he had not been able to ascertain.

Colonel J. T. Smith said, as far as he could make out the Table on which the results given in the Paper were founded, there was one important element neglected, viz., that half the value of the produce was taken by the Government in assessment. The results of commercial speculation depended upon, first, what was paid for an article, and, secondly, upon what it could be sold for: To begin with the sale of the water, he had not been able to make out how it was deduced that £1 1*s*. per acre irrigated was the value; but the value so calculated was not important, for when discussing a commercial speculation connected with a concession from the Government, the company was bound to accept the terms of the concession; and the Government concession of the privilege of storing water in South India was connected with a condition to sell it at the rate of 12*s*. per acre irrigated. Therefore he conceived the real commercial result ought to be based upon the 12*s*. per acre, and it would mislead the public if they were induced to believe that a return of 46 per cent. was to be obtained by selling the water at a guinea when there was actually no power to do so. He, therefore, concluded that the results ought to be based upon 12*s*. per acre.[1]

He now came to the cost of the water. He thought the Author had acted with great impartiality in the statements of cost, yet he could not agree with the results. The calculation was based upon an average reservoir, able to store water at the rate of 4,250 cubic yards per £1. That was an imaginary reservoir; but a description was more particularly given of one reservoir which was proposed to be immediately restored, viz., the Mudduk Masoor tank. He would say with regard to that, as well as with regard to the statement of past profit derived from Government irrigation works, that it was one thing to construct a work, and another thing to take a work already constructed, and simply out of order. If he brought forward a project for taking up a large number of houses out of repair, and showed that by putting them into good order he could make 23 per cent. by it, the scheme would appear very attractive; but the question would arise—who would give so valuable a concession? The Government, as possessors of these old tanks, had little to do to put them in order, and consequently made very large profits. It was stated that the Mudduk Masoor reservoir was about 40 square miles in superficial area when full; and that it contained 1,400,000,000 cubic yards of water. It was proposed to lower the dam from 90 or 108 feet height to about 70 feet, and then the area would be about 24 square miles. The Author, by experiments on the spot, found that an average monsoon rainfall yielded about 668,000,000 cubic yards of water; consequently he proposed to provide a reservoir which would contain a little short of that, viz., 644,000,000 cubic yards, which would be the capacity of the Masoor reservoir with a dam 70 feet high. Upon this it might be observed that, unless the monsoons were of great uniformity, it was not sufficient to provide reservoirs equal to the average expected: they ought to be capable of holding the maximum as well as the minimum rainfall. The question, therefore, arose whether the district was one in which the seasons were uniform, or fluctuating. He had the following reason to believe the seasons were extremely fluctuating. It so happened that the Company who proposed to construct this reservoir suggested another in the same neighbourhood, called the Maury tank. The Chief Engineer sent home a report, founded upon observations, the result of which showed that there was abundance of water to fill the tank, and it was resolved to make application to the Government for it. But the Government hesitated to grant the concession, on the ground, partly, that the supply of water was insignificant compared with what was estimated, and partly because it was not more than the country required, and they therefore finally resolved to keep it for the use of the inhabitants. He had also been informed privately, but on good authority, that a similar hesitation was now felt as to granting the concession of the Masoor tank, and for the same reasons, namely, that the supply of water was much less than was supposed, and not more than was required for existing demands. Now he did not attribute these different estimates of the probable rainfall to errors of observation on the part of the various officers who made them, but to the fact that they were made at different times, and that the fall of rain in the district was very uncertain. Hence if the parties constructing such reservoirs made their calculations on the ground of storing the average monsoon rainfall, they must have a larger tank than the average rainfall would fill. Calculating without this would tell in one of two ways. Either the tank would cost more from building it larger, or there would be less water on the average than was anticipated; and on those grounds he thought some deductions ought to be made from the Author's estimate of the value of the produce of these tanks.

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[1] The Author guarded his statements by the express provision that the actual values were to be realised, but there was no such qualification in the second conclusion submitted to the meeting; and although it is quite possible that an increase in the water-rate might hereafter be allowed, yet such an increase ought not to be assumed in stating the present value of a mercantile speculation.—J. T. S.

The next point was the evaporation from the tank. The specimen or representive tank was supposed to contain 4,250 cubic yards for every £1 sterling laid out upon it; which, allowing for interest on the money during construction, was calculated to yield 340 cubic yards per rupee; but it was necessary to modify this calculation, because it was one thing to have the water in the tank, and another to have it on the land.

Reverting to the Mudduk Masoor tank of 24 square miles area and 640 millions of cubic yards capacity, the Author had estimated the evaporation during four months from that tank while it was being emptied, and his calculations had been made upon proper data which corresponded with experiments carried out by order of the Madras Government, whereby it was deduced that in the middle of the tank the evaporation was about one-third of an inch per day, or 10 inches per month, which in four months amounted to 40 inches. This result was however subject to a deduction of one-half, inasmuch as there was a reduction of surface from 24 square miles at the beginning of the discharge to a greatly diminished surface at the end. That brought the evaporation down to 20 inches in the four months, over a surface of 24 square miles, and amounted to 40 million cubic yards, or 6⅔ per cent. of the 640 millions of cubic yards which the Masoor tank was to hold. Now, 6⅔ per cent. during the four months was equal to twenty per cent. during the year. For it must be noted that, although it was quite sufficient to calculate the evaporation from the surface of the reservoir during the months of discharge only, if the object was, from a given quantity at the beginning of the discharge, to determine the quantity which left the reservoir, yet the case was different when, with a given average monsoon rainfall, it was intended to ascertain the loss by evaporation during the time of its collection in the reservoir, its preservation there, and also its discharge. For this purpose the evaporation for the whole year must be taken into account, at an average of half the surface during collection and discharge, and during the remainder as for the whole surface. Hence the loss for the whole year would be 20 per cent. without reckoning the full rate during the interval of repose.[1] And here he would mention that when the experiments were made on which the rule of the irrigation department was founded, viz., that ⅓rd of an inch per day was evaporated from the middle of a large tank, the gentleman who had charge of the experiments reported at the end of the season that ⅝ of what had left the tank left by evaporation, and only ⅜ had gone on the land: that was, 62½ per cent. was evaporated, and only 37½ per cent. had gone on to the land: the fields referred to being in the immediate vicinity of the tank, so that there could not have been a length of more than from 10 to 20 miles of irrigation channels.

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[1] Owing to a strange clerical error, the Author had omitted to make the deduction of 12 per cent. which he allowed, so that the £1 9*s*. 5*d*. per acre was based upon the supposition that every drop of water in the tank was spread upon the land.—J. T. S.

The next question to be considered was that the water let out of the Masoor tank did not irrigate the fields immediately, but went down the bed of a river for 200 miles. He believed the bed was in some places rocky, and in others sandy and absorbent. Thus the water was in motion for 200 miles before it reached the irrigation canal, and an allowance must be made for evaporation and absorption. After reaching the head sluices the water had, on the average, 100 miles of main canal to traverse, and that canal was very leaky. There was a great deal of loss by leakage, not, however, owing to any fault of the Engineers, for they had done their duty perfectly. But it was leaky, partly owing to the extreme badness of the soil, and partly because, owing to financial considerations, it was thought advisable to let it remain as it was for the present, as it would have required a considerable expenditure of money to have made those banks tight; and it was thought better to postpone that expense till the water was more valuable than it would be for the first few years. In addition to the distance already traversed, there were between 300 and 400 miles of distributing channels finished, which might possibly be increased to 500 or 600 miles before they were all completed.[1] He would prefer that others should judge what was the proper allowance to be made for the losses referred to—first, by evaporation in the reservoir; secondly, in the bed of the river; thirdly, by leakage and evaporation in the main canal; and fourthly, in the distributing channels.

In estimating a scheme of this kind, and calculating the financial results, it was proper to be on the safe side. The Government decided that 2 cubic yards per hour for each acre was necessary; but he observed that Mr. Gordon had calculated 5,000 cubic yards per acre only. He thought it should be 6,000 cubic yards. The average time of cultivation was about one hundred and thirty days, and 2 cubic yards per hour per acre for one hundred and thirty days was more than 6,000 cubic yards. Again, the mere evaporation alone, from the surface, at the rate he had stated, namely, $\frac{1}{3}$ of an inch per day, would come to 8,000 cubic yards for the six months, and more than 5,800 cubic yards for one hundred and thirty days; and hence, taking also into consideration absorption and other losses, he thought 6,000 cubic yards was the least that ought to be allowed for.

To recapitulate his remarks respecting the formation of the tanks,

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[1] It was not hereby intended that the water must traverse these 300 or 400 miles; the distance run would of course vary with the situation, from a few chains possibly, to a number of miles.—J. T. S.

Mr. Gordon's estimate, after allowing for interest during construction, was 340 cubic yards per rupee. Now he had given reasons for thinking there ought to be an increase in that estimate, or, in other words, a diminution in the number of cubic yards stored per rupee. If, for instance, the Masoor dam were built of the full size, to secure the whole monsoon rainfall in every year, it would cost double the money estimated by the Author, and instead of 960 cubic yards per rupee, there would only be 480 cubic yards. In the same way, in regard to the specimen tank, instead of 340 cubic yards per rupee, there ought to be much less, if the whole rainfall were calculated. As he wished to take a most moderate view of the case, he would only strike off the 40 cubic yards from the 340, leaving the estimate at 300 cubic yards per rupee. But this did not represent the quantity actually put on the field; and in his opinion, if the Madras Irrigation and Canal Company got one half of the water upon the fields, they would do very well. In that case they would have 150 cubic yards per rupee on the field, and the 6,000 cubic yards required for the irrigation of each acre would cost Rs. 40, for which they would receive Rs. 6 return. Now Rs. 6 for every Rs. 40 amounted to 15 per cent.; and if 3 per cent. were allowed for repairs, superintendence, and management, it left 12 per cent. to be divided between the proprietors of the old and new works; and he believed this to be a fair estimate. He had no wish to exaggerate; but he thought it was right to sift an important question like this, and if he had made any mistake, the Chief Engineer of the Company would no doubt correct him.

There was one more point he must advert to—a point of expenditure, viz., Who was to insure these large works against accident after completion? He thought Government would, on general principles, be disinclined to grant concessions for reservoirs, if they believed the parties were likely to realise 46 per cent. from them. They might still more hesitate to give a concession unless they had security that, in case of failure, there would be some funds to meet the loss. To give an idea of the magnitude of these works, he might state that the proposed reservoirs were four hundred times the size of the Bradford reservoir, near Sheffield, the failure of which caused so much disaster and loss of life and property some years ago. It was true the country was not densely populated, but there were towns and villages, and a good many inhabitants within reach of danger. Therefore it might be supposed the Government would require security, in connection with works of the magnitude referred to, and the provision of some party responsible for, and able to make good, any damage.

Mr. **Russel Aitken** said, the quantity of water required to irrigate a certain area depended very much upon the nature of the soil, as well as the crops to be raised. In the case of sandy soils a large quantity was wasted, as the water soaked into the ground, thereby raising the spring-level of the country. The value of water depended very much upon the nature of the rainfall. In the Concan in Bombay and other places, where the monsoon rainfall was most abundant, a supply for one crop could always be depended upon, but this was not the case in other parts of India. Then, as regarded the crops raised, in some parts the produce could not be disposed of without great cost for land-carriage. The distance from a market made an enormous difference in the value of water for irrigation purposes. Those who embarked in irrigation projects were apt to consider that, as soon as the water was provided, it would be taken up immediately; but that was often not the case. In the first place, there must be population to cultivate the ground; then the cultivators must acquire capital to buy bullocks, build houses, and obtain agricultural implements. Therefore the expectation of an immediate return from these works was, he thought, a great mistake. The returns from the Ganges canal varied from 1 per cent. up to 2½ per cent., after paying working cost, which, even in a fully-developed canal, amounted to 25 per cent. of the total revenue; and it was only in 1868-9 that it paid 7¼ per cent., and that was an exceptional year. In the case of the large returns reported of some of the Government works, they had been constructed under very favourable circumstances, so far as regarded the natural facilities afforded by the ground, and also by the comparatively low rates of labour which then prevailed.

Large canals in the deltas of Madras had been constructed for about Rs. 7,000 per mile, and that was a very cheap rate when compared with some new canals there, the construction of which had cost at least Rs. 70,000 per mile. Thus, returns which now paid 30, 40, or 50 per cent. on the smaller cost, would give but 3, 4, or 5 per cent. on the larger expenditure; so that the first cost of the works produced a material effect upon the returns of profits.

The actual value of water in any canal varied so much that no definite conclusions could be given. On the Ganges and the Eastern Jumna canals, the annual revenue for a discharge of one cubic foot of water per second was as under:

	Ganges Canal.	Eastern Jumna Canal.
	Rupees.	Rupees.
1866–67	374	522
1867–68	390	519
1868–69	525	653

The water-rate was only about Rs. 2 per acre per crop; whereas in Madras and Bombay it was much higher.

In Bombay he had made a number of observations fruitlessly to find the quantity of water required to cultivate land. Waste, as in waterworks in England, was the chief difficulty. As to the different values of water, he might give one instance to show how it varied. In calculating the value of water from a proposed reservoir about 50 miles from the town of Bombay, he came to the conclusion that a cubic foot per second, for eight months of the year, was worth Rs. 715 per annum for field cultivation, while in the Island of Bombay water was worth, for market gardens, Rs. 8,200 per cubic foot per second, or nearly twelve times as much. It depended upon the crops cultivated, the nearness of the market, and whether there was population to take up the water supplied.

Although irrigation works in India did not, as a general rule, offer a field for profitable speculative investment, yet there could be no doubt as to the duty of the Government of India in this matter. Not only did the Government get large revenues from the water-rates, but canals contributed to the revenue in many indirect ways. In 1868-9 there would have been a famine in North-western India but for the Ganges canal and other canals. The Government, being the proprietors of the land, derived revenues from the land-tax, as well as the water-rates; and if there had been no crops to gather, the Government would have lost the land-tax, whereas they had the benefit of both land-tax and water-rates. In many places, where it would not pay a private company to construct works for irrigation purposes, it paid the Government to do so. In Poonah, a large garrison town, the Government were constructing irrigation works; but he doubted whether they would give any considerable return upon the outlay, though, when the effects of irrigation in reducing the price of forage, and other benefits resulting from a supply of water were considered, there was no doubt whatever of the necessity for those works being undertaken.

One other point he would mention, viz., the difficulty there was in following this discussion owing to the varying quantities that were spoken of. In Madras the calculations were at per cubic yard per hour; in the north-west the rates were taken at per cubic foot per second; while in Bombay he had been in the habit of calculating in million gallons. It was very desirable that the measurement of water in irrigation works should be reduced uniformly to the cubic metre per minute, which would be better than when several varying standards were employed.

Mr. J. Aird observed that, from the drawings there appeared to be a total absence of any puddle-gutter—a work which was accustomed to be regarded as an important element in the construction of large reservoir banks. Experience showed that, when a leak occurred in a reservoir bank, it was difficult to stop it in the absence of a puddle-gutter, or some protecting material of that sort. He would be glad to hear what means had been taken to protect the slopes of these reservoirs. If they were of the enormous area described, with the varying climate, heavy rains, and strong winds, they must be exposed at times to much wash, and without adequate protection upon the slopes there might be considerable danger.

Mr. A. JACOB stated that there was a large waste of water in the beds of the rivers. He had gauged many rivers in India, and found that the amount of water discharged at the head was nearly the same as at the outfall. The tributary streams discharging into the main channel were numerous, and it was evident that much of the water must be lost by evaporation. There was an old saying in India, that irrigation works on rivers increased the discharge of the river; or, in other words, that there was more water got out of the river than it appeared to discharge above the works. Keeping this in view, it was surprising to see the important results produced by placing dams across rivers at intervals of 5 or 6 miles asunder.

He dissented, to some extent, from the views expressed by the Author as to the superiority of high embankments. No doubt a reservoir of great depth gave a less degree of evaporation, *cæteris paribus*, than a shallow one. But shallow tanks were easier of construction by native labour, and for a given quantity of earthwork the tanks were cheaper, because the material was at hand; and when the work was performed by basket-labour, everything, as regarded cost, depended on the distance from which suitable material had to be carried, which in large banks was sometimes very great. At the present time the Government fixed 12*s.* as the basis on which the financial return was to be calculated. Seven or eight years ago, a uniform rate of Rs. 1 per acre was fixed by Government; and though he had matured many projects, none of them could be calculated to pay on such a low basis. It seemed very small, when it was notorious that the natives were prepared to take water at Rs. 15 to 20 per acre irrigated. Unless the Government would charge at a fairly remunerative rate, as the natives would do themselves, neither Government nor private companies could expect to get a reasonable return for their money.

Mr. HEMANS, Vice-President, remarked that 5,000 cubic yards turned into cubic metres, or tons, represented 3,750 tons, equal to a depth of 37½ inches of water per acre. That, at the rate of 12*s.*

per acre, would be at the extremely low price of $\frac{3}{100}$ths of 1*d.* per ton. He did not understand how a crop of rice could absorb such a large amount of water as 3,750 tons per acre. Colonel Smith said it should be 6,000 cubic yards. It was customary in England to irrigate with diluted sewage at the rate of 5,000 tons per acre; but from that land 60 or 70 tons per acre per annum of the rankest and richest grass crops were taken, in a series of crops of 5 or 6 tons each. He wanted to know how that quantity of water could be absorbed or necessary, in addition to the natural rainfall, and whether the quantity stated was applied to one crop or two crops of rice per annum; and further, how it was possible the profits stated could result from the price of $\frac{3}{100}$ths of 1*d.* per ton of water.

Mr. H. CONYBEARE had given some attention to the impounding of water, having constructed for the water supply of Bombay[1] a reservoir covering 1,400 acres, and in parts upwards of 80 feet in depth, which he believed was one of the largest modern works of this description. No one could have witnessed the almost magical results of irrigation in tropical and semi-tropical climates, in converting a desert into a garden, without feeling a strong desire to be able to make out a good case in favour of the extension of irrigation as a commercial undertaking. It was therefore with great regret that he had come to the conclusion, that no such case had as yet been made out, at least as regarded tank irrigation. Obviously the most important element in the calculation was the cost at which the water could be stored; but, unfortunately, there was still great uncertainty, and widely differing opinions, as to the number of cubic yards of water that could, under average circumstances, be impounded for a rupee. The Author of the Paper had assumed the quantity to be 700 cubic yards in favourable cases, and 340 cubic yards in unfavourable cases. The cost of the earthwork in the dam was taken at only 3*d.* per cubic yard, but it was doubtful whether such work could be executed under 6*d.* per yard. Moreover, these calculations appeared to be entirely based on estimates; whereas on a point of this practical nature, and of such great importance, it was only safe to rely on the basis of accomplished facts. To be satisfied on such a matter there should be official records showing the actual particulars of cost, and also the contoured plans of a number of reservoirs actually executed, by which the storage capacity of each might be computed, together with such detailed drawings of the dams, &c., as would allow of the quantities of the work involved in impounding the water being accurately checked; such data, in fact, as had been afforded, in respect to the irrigating tanks in Ajmeer and Mairwara, by Colonel Dixon's work.[1] A book had been published by Sir A. Cotton,[2] in which reference was made to the enormous returns that works of irrigation were calculated to yield in India as commercial investments, and in which this work of Colonel Dixon's was grievously misquoted. Sir A. Cotton stated (page 123) that under ordinary circumstances storage reservoirs could be constructed at as low a rate as R. 1 (2 shillings) for each 2,000 cubic yards of water stored, and under favourable circumstances, to store thrice the amount; and he stated (page 254) that in the one hundred and twelve irrigating reservoirs constructed by Colonel Dixon in Ajmeer, in Rajpootana, the average cost of water was one rupee for each 8,000 cubic yards of water stored.

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[1] *Vide* Minutes of Proceedings, Inst. C.E., Vol. xvii., p. 555.

Colonel Dixon's work for impounding water in Rajpootana, of which Sir A. Cotton spoke so highly, afforded the most economical examples as yet on record of works of this description. The Government of India were of opinion that "it would have been impossible, in almost any part of India, or under any other superintendence than Major Dixon's, to have constructed such works." Accordingly the Court of Directors requested that Colonel Dixon would prepare a report of what he had effected in Mairwara, and a detailed account of the improvements recently made in Ajmeer, accompanied by scientific plans, sections, and drawings, of his more important works, founded on actual survey and measurement. They further ordered that, when prepared, such report and illustrations should be printed and circulated at the expense of the Government of India, for the guidance of officers engaged in similar operations. The report so called for was subsequently published in a quarto volume, containing scientific descriptions and illustrations of eight of Colonel Dixon's principal storage reservoirs, together with a general description of the remainder.

A comparison between the rates at which Sir A. Cotton so positively calculated on impounding water, and at which he stated that Colonel Dixon had impounded water, with those actually obtained in the most economical works of Colonel Dixon's extensive practice in Rajpootana, would afford no unfair criterion for testing the general accuracy of Sir A. Cotton's figures and calculations. It would appear, on instituting such comparison, that Sir A. Cotton had calculated the cost of storing water about ten times too low; and that the final cipher ought in most cases to be abated from his numerical statements. For it was to be presumed that the eight examples of reservoirs which Colonel Dixon had selected for detailed illustration, out of a total of one hundred and twelve, would be considerably more than average specimens; as it was, indeed, known they were from the particulars afforded by his tables regarding his less important and unillustrated works.[1] Yet, on analysing the elements of the eight model works so selected, it appeared the most economical result obtained was 688 cubic yards of water per Rupee, the lowest only 102 cubic yards per Rupee, and that the average number of cubic yards of water stored for each Rupee, expended merely in labour and materials, was only 284 cubic yards per Rupee, and for four of the eight model examples, was under 200 cubic yards per Rupee. Whereas Sir A. Cotton stated (p. 123), "I calculate that water can be stored at 2,000 cubic yards per Rupee (2 shillings), an estimate which is the result of long experience among the tanks of the Carnatic. Without any remarkable advantage in the site, a bund may be made almost anywhere at this rate; but in many situations where the form of the ground favours it, thrice this amount may be stored for a Rupee (2 shillings)." He also estimated the average results of Colonel Dixon's practice in Ajmeer at 8,000 cubic yards per Rupee. Moreover, Colonel Dixon's tanks were constructed at exceptionally low rates. The masonry in mortar was only 1*s.* 6*d.* per cubic yard, and the earthwork, "well beaten and rammed," was executed at the low rate of 1⅝*d.* per cubic yard. Now, Engineers of Indian experience would know that, earthworks of that sort could not be sublet in India at the present time at less than four times the rate that Colonel Dixon paid for his work. Sir A. Cotton remarked in his book, that if these reservoirs had been larger (the eight selected for illustration in this work were much larger than the average of such works in India), the water could have been more economically stored. That was true theoretically; but, on the other hand, the sites where enormously large quantities of water could be economically stored were very exceptional, and where they did occur they usually involved exceptional sources of expense, which detracted materially from their theoretical economy. In the case of the large reservoir which he had made at Bombay, covering 1,400 acres, and 80 feet deep, with every attention to economy, he was only able to store 162 cubic yards per Rupee, and that work was done by contract. Therefore he was afraid no case had been made out for the extension of tank irrigation, as a commercial speculation, in India. The results were so uncertain; there were so many circumstances to cause variation in the profits; and, as he had shown, the actual cost of impounding water was so much greater than it was usually stated to be. But

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[1] *Vide* "Sketch of Mairwara; giving a brief account of the origin and habits of the Mairs; their subjugation by a British force; their civilisation, and conversion into an industrious peasantry; with descriptions of various works of irrigation in Mairwara and Ajmeer, &c." By Lieut.-Col. C. J. Dixon. 4to. Maps, plans, and views. London, 1850.

[2] *Vide* "Public Works in India." By Lieut.-Col. A. Cotton. 8vo. Madras, 1854.

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[1] The following Table, compiled from the scientific descriptions and illustrations of eight of Colonel Dixon's principal works at Mairwara and Ajmeer, will give the principal elements and the cost of water-storage in each. Colonel Dixon gave no contoured plans of the sites, from which the cubical contents might be exactly ascertained; but it was found in practice, that the area of a reservoir multiplied by two-thirds of its greatest depth would afford a fair rough approximation—and usually in excess rather than otherwise—of its cubical contents; and the contents of Colonel Dixon's reservoirs had been thus calculated.

TABLE showing the Cost of IMPOUNDING WATER in RAJPOOTANA (compiled from COLONEL DIXON'S Work.)

NAME OF TANK.	Surface Area in Square Yards.	Greatest Depth in Yards.	Contents in Cubic Yards (being two-thirds of greatest Depth into Area).	Cost (exclusive of Survey, Superintendence, &c. &c.).	No. of Cubic Yards stored per Rupee.	Lineal Yards of Dam to Acre of Surface.	Proportion borne by Length of Dam to Total Enceinte.	Description of Dam.
				Rs. = 2s.				
1 Kabra . .	968,000	$6\frac{2}{3}$	4,302,222	6,248	688	$10\frac{1}{3}$	$\frac{1}{22}$	Earth faced with masonry.
2 Juwaja . .	1,161,600	5	387,200	3,784	102	22	$\frac{1}{8}$	Earth faced with loose rough stone.
3 Roopana .	135,520	6	524,080	2,205	246	..	..	Earth faced with masonry.
4 Gohana . .	503,360	8	2,684,586	4,269	629	$1\frac{1}{2}$	$\frac{1}{17}$	Do. do.
5 Kalee Kankur	616,666	9	3,699,996	16,549	223	9	$\frac{1}{8}$	
6 Lohurwara .	780,000	5	3,900,000	7,743	503	49	$\frac{1}{2}$	Do. do.
7 Durathoo .	813,750	$8\frac{2}{3}$	4,701,666	25,995	188	22	$\frac{1}{4}$	
8 Sreenuggur .	526,444	$8\frac{1}{3}$	2,924,688	14,648	200	5	$\frac{1}{8}$	
Total of 8 Tanks			23,142,438	81,441	..			
No. of cubic yards of water stored for one Rupee—average of the 8 tanks . .			.. ..	.. ..	284			

The rates at which the Kabra embankments were constructed were as follows: Lime masonry, 1*s.* 6*d.* per cubic yard; earth in bank, well beaten and rammed, $1\frac{5}{8}$*d.* per cubic yard. The rates at the other reservoirs were nearly the same.

there were a very large number of ancient tanks throughout India and Ceylon, that had become breached for want of a waste weir, the repair of which could not fail to prove remunerative as a commercial investment. Even in cases where irrigation would not answer as a commercial investment to outsiders, it would still be worth the while of the Government to undertake such works; because in most parts of India Government stood in the position of being the universal landlord, and the amount of indirect profit they would get in saving the remissions of land-tax in seasons of drought would make to them the difference between a loss and a profit. Moreover, were a large proportion of the land in any district under irrigation, famine and its incidental calamities and losses would be rendered impossible. There was, therefore, no question regarding the enormous importance to the Government of the extension of irrigation.

He was not acquainted with any dam in India, constructed by natives, which had a puddle wall; but the bank was usually an enormous mass of earthwork, and being built up with basket-labour, and being thus deposited in very thin layers, by means of the constant trampling of the men, women, and children, employed in carrying the baskets, the whole structure was rendered almost as compact and impervious as puddle. Some of the great reservoir dams in Central India, like that of the Saugur lake, consisted of two parallel walls enormously massive, and built at so considerable a distance apart, that in the interval (filled in with well-packed earth) there were often forest trees and hamlets: thus the fort, and a portion of the city of Saugur were built on the dam of the Saugur lake. He knew of no native reservoir with a bye-wash, and even a waste weir was often absent.

Mr. F. C. **Danvers** said he had endeavoured to ascertain, from published reports, the commercial value of water in India, and had been struck with the variation of returns from canal and other irrigation works. He found, from the reports annually issued by the Government, that the sum of £5,712,000 had been spent upon irrigation works in Madras, the Punjab, and the North-western Provinces, the returns upon which were as follows: Madras, 29·41 per cent.; Punjab, 7·01 per cent.; and the North-west Provinces, 5·06 per cent.; yielding an average return, on the whole, of 10·5 per cent.

In Madras, of the thirty-two principal irrigation works, eighteen showed a balance of income over expenditure, and fourteen yielded no direct net return, but showed a deficit. Of the remunerative works he might mention the following:

	Cost.	Net Revenue.	Return.
	£	£	Per Cent.
Lower Coleroon	11,647	39,442	Over 338
Upper Coleroon	23,986	42,561	177
Vellaur Anicut	8,215	10,442	127
Godavery Anicut	432,886	175,116	40·4
Pennair.	59,050	6,470	Nearly 11
Kristna Anicut	271,720	20,747	7·6

In the Punjab the direct income gave 7·01 per cent.; but if the indirect income was added, the return was equal to 12·52 per cent. upon the capital outlay for irrigation works. The indirect revenue, in the shape of enhanced land-tax, arising from the beneficial effects of irrigation upon the land, was calculated at 12 annas, or 1*s.* 6*d.* per acre. Of the six large irrigation works in the Punjab only two returned a profit from direct revenue, viz., the Western Jumna and the Baree Doab; but including indirect profits, all but the Upper Sutlej were profitable. The Western Jumna canal showed a direct net profit of 35·82 per cent.; and the Baree Doab of only 2·86 per cent. The former was one of the oldest of the Mogul canals, and irrigated 496,543 acres; the latter, a work of modern times, irrigated 233,927 acres.

It had been stated that, in the North-west Provinces, the net returns were 5·06 per cent. on the entire capital expended; but a portion of the expenditure was upon works not yet opened. With that deduction the return was equal to 5·13 per cent., and it was estimated that if a fair addition was made for increase of land revenue, the returns would be equal to upwards of 8 per cent. Of the seven large canal systems in the North-west Provinces only three returned a net profit, viz., the Ganges, the Eastern Jumna, and the Dhoon canals. The other four worked at a loss, so far as direct revenue returns were concerned. The Ganges canal showed great fluctuations in the returns obtained respectively in seasons of drought and good monsoon rain. In the year 1868-9 the net profit was 7 per cent., and in the following year only 4 per cent., which was mainly owing to the difference of rainfall. The Eastern Jumna canal returned a profit of 23·33 per cent., and the Dhoon of only 2·58 per cent.

With reference to the value of water, Colonel Dickens, in his Report on the Soane canal, laid it down that, "Excepting in the rich land near the Ganges and a few other favoured spots, the unirrigated crops of wheat and barley are very scanty, and are said to produce only 256 to 640 lbs. per acre; and those irrigated once or twice yield only from 512 to 1,024 lbs. per acre: irrigated three times, the crop is said to yield from 896 to 1,280 lbs. per acre; but the people told me if they could irrigate four times, using abundance of water, they would get from 1,280 to 1,920 lbs. per acre."[1] To irrigate thoroughly, Colonel Dickens considered 17,600 cubic feet of water per acre were necessary for the season. The average assumed in drawing out the projects for the Baree Doab and the Ganges canals, derived from data afforded by the Jumna canals, was that each cubic foot of discharge per second was capable of actually irrigating 218 acres. In the Soane canal project, Colonel Dickens estimated the effective duty of water at a somewhat higher rate.

The actual results obtained from some of the principal canals in Northern India were as follow: Area irrigated per cubic foot per second of water actually employed in irrigation, after deducting volumes escaping at terminals—

	Ganges.	E. Jumna.	W. Jumna.	Baree Doab.
Acres	186·03	268	240	154·91

He was unable to obtain definite information as to the extent irrigated by a cubic foot of water per second per acre in the Madras Presidency; but he had seen a calculation in which the rate laid down was 2 cubic yards per hour per acre, which was equivalent to 200 acres for each cubic foot of water per second, and that agreed nearly with the estimate for the canals of the North-west Provinces. In older works, as had been already shown, the value obtained was higher, viz., 240 acres to 268 acres; while the Ganges and the Baree Doab yielded the less return of 186 acres and 154 acres respectively.

The water-rates realised per cubic foot of discharge per second were—Ganges, Rs. 378; Eastern Jumna, Rs. 538; Western Jumna, Rs. 499; Baree Doab, Rs. 127·9: and the water-rate per acre irrigated was nearly the same in each case, viz., Ganges, Rs. 2·25; Eastern Jumna, Rs. 2·32; Western Jumna, Rs. 2·41; and Baree Doab, Rs. 2·35. This was for the autumn and spring crops. The rate varied slightly according to the crop; thus, on the Ganges canal, for the autumn crop it was Rs. 2·57 per acre; and for the spring crop, Rs. 2·00 per acre: the mean being Rs. 2·25.

In conclusion, he would draw attention to recent numbers of "Professional Papers on Indian Engineering," in which the semi-official correspondence addressed to the private secretary to the Viceroy, by Major Corbett, B.S.C., on the question of, "Is Irrigation necessary in Upper India?"[1] was published by desire of the Viceroy. It was contended that superior cultivation to what now exists was alone necessary; that at present the ground was only scratched a few inches deep with the native plough; and below that there was a hard crust which prevented the water filtering through; and that if that was broken up, and the cultivation carried deeper, there would not be the same necessity for irrigation, because evaporation from the land would not take place to so great an extent.

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[1] *Vide* "A Project for Canals of Irrigation and Navigation from the River Soane in South Behar," p. xix. 8vo. Calcutta, 1861.

Major J. BROWNE, R.E., stated that in Upper India tanks were not generally employed, as the slope of the ground was so great that it would require dams of great height to hold in even a moderate supply of water. In some parts, the foot of the hills afforded an opportunity for building tanks; but they were on a small scale, and generally ended by drying up and being taken up for cultivation. Mr. Gordon had mentioned that the proper method of defending the masonry in falls, against the violence of the water going over them, was to provide water cushions. No doubt these were beneficial; but another method was employed in the canals of Upper India, which he believed was more efficient; and that was to place on the crest of the dams stout timber gratings, composed of baulks about 6 inches by 6 inches, and about 2 or 3 inches apart, and slightly slanting upwards. The effect of this grating was to cause the water going over the crest of the weir to fall in thin films, and consequently with less destructive effect; the velocity of the water was also thereby materially checked. Besides, in Upper India destruction was caused by the drift logs that floated down the canals in floods; and these great logs, 20 or 30 feet long, taking headers over the falls, smashed everything before them; but the grating protected the masonry from this cause of demolition. These gratings had been used for many years by Colonel Dyas, and they answered as a most efficient protection to the masonry of the falls.

Mr. Latham had mentioned, with regard to the discharge to be provided for in catchment basins, that the formula was represented by—The discharge, equal to a constant quantity, multiplied by the drainage area, raised to the power of $\frac{3}{4}$rds. That was Colonel

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[1] *Vide* "Professional Papers on Indian Engineering." Second series. Vol. i., pp. 3-20, 101-125.

Dickens' formula, with one slight difference, viz., that the drainage area was raised to the power of $\frac{3}{4}$ths instead of $\frac{2}{3}$rds. This did not make much difference in a small drainage area, but it did in large catchment basins.

At the foot of the Himalayas the rainfall was very great, and exceeded anything that had been mentioned; coming up to 4, 4½, and 5 inches per hour. In such districts the formula which gave the best result, taking the discharge in cubic feet per second, and the drainage area in square miles, was—Discharge equal to 1,200, multiplied by the drainage area raised to the power of $\frac{3}{4}$. He believed the circumstances in Madras were somewhat different; but in Upper India, and particularly in the Punjab, it appeared to him that canal irrigation was largely supplied to districts where it was not so much required, and denied to districts where it was most required. The rainfall in the Punjab varied inversely as the distance from the great Himalayan chain which ran to the north, and on which the rainfall varied from 80 to 210 inches. In the Sub-Himalayas it varied from 40 to 60 inches; at 120 miles from the hills it was not more than 30 or 40 inches; going to 250 or 300 miles from the hills, the rainfall came down as low as 3 or 4 inches; while in Scinde it was scarcely more than 2 or 3 inches.

The depth at which water was found in wells followed the same rule, varying as the distance from the mountains. Where the rainfall was not under 30 inches, and the depth of the wells did not exceed 30 feet, canal irrigation, though advisable, was not absolutely necessary. The great difficulty was to get sufficient water to irrigate those districts where canal irrigation was alone possible. Most of the water that came down the Baree Doab canal, and a great portion of that which came down the Ganges canal, was taken up by those districts where the wells were not more than 30 feet deep; and the result was that the villagers had allowed their wells to choke up, and had become entirely dependent upon the canals.

The moral of this was, that in the great projects that had now to be taken in hand, well irrigation should not be entirely lost sight of. There was no water to spare; and it seemed to him economy had not been observed, where canals were employed in districts where irrigation could be practised, even to a small extent, by wells. No doubt canals must sometimes be taken through districts where well irrigation was possible; but the canal ought to go through such districts not as an irrigation canal, but merely as a channel conveying water down to the lower districts, where the rainfall was so small that irrigation was absolutely necessary. He was aware that there was a great deal to be said against well-irrigation, and that it cost so many pounds, shillings, and pence, to hoist so many cubic feet of water from a given depth. As a purely mechanical arrangement, he did not put well-irrigation in competition with canal-irrigation; but in a commercial and social point of view there was a great deal to be said in favour of well-irrigation. Except perhaps the Civil Courts, there was no greater cause of discontent in India than canal-irrigation. Villagers who used their own wells were not exposed to be bullied by canal understrappers, who might threaten to cut off the water, and compel their attendance in Civil Courts; and they were free from official restrictions in the distribution of the water. Then, again, as a commercial speculation, canal companies must necessarily lay out a great sum, which could not return any interest at first starting, and probably for a very long time; whereas money laid out in wells, if it paid at all, would pay very quickly; as a well could be started, and be in full operation, if not more than 30 feet deep, within a month after it was begun. A company for well irrigation could feel its way without risk; whereas a canal company must lay out money freely, and getting no return for a long time, might find itself, perhaps after twenty years, in the receipt of 1 per cent. dividend per annum. As to hoisting water from the well, in many parts of India, particularly below the hills, the wind was for the most part very steady during the morning and evening, and a good deal could be done by windmills. Then, again, by irrigating by wells the waste was avoided, which always resulted more or less from canal-irrigation, and spoilt the crops by souring and oversoaking the soil. He had always understood from such cultivators as he had spoken to, that crops raised from well water were of a better quality than those raised from canal water. He could not say whether it was due to the higher temperature of the well water, or to any chemical difference in the water itself, but canal-raised were, he believed, generally inferior to well-raised crops.

He did not wish it to be supposed that he at all undervalued the vast benefits of canals. They were indispensable, no doubt, where irrigation could not be obtained by other means; but in the ambitious projects of the Government and of private companies, he thought they had too much lost sight of the question of well-irrigation; and it had apparently been forgotten that there was possibly as much water below as above the surface. It was admitted, that in Upper India, there was barely enough water on the surface to irrigate those districts where well-irrigation could not be employed. Therefore, for every acre of land irrigated by canals which might have been irrigated by wells, an equal acreage in another part of the province was condemned to perpetual barrenness; and this would be the case whenever canal water was supplied to districts where well-irrigation was possible.

In a social and commercial point of view irrigation by wells had many advantages, although as a mechanical arrangement he did not wish to defend it. It seemed to him that, with the improved means of communication in India, well-irrigation was a means of preventing, to a great extent, and at a very early period, the recurrence of those famines which might come at any moment, and which might occur for years before those more ambitious projects, which he did not, however, undervalue, had been well started, and had begun to do any good to the country.

Mr. G. Gordon, in reply upon the discussion, said Mr. Latham had inquired what allowance had been made for the discharge of storm-water from the reservoirs, and as to the calculation of it in reference to maximum rainfalls in India. He had used no formulæ. He had ascertained what the maximum flood discharge of the rivers had been during a period of fifteen or twenty years, and that was exceeded by a recorded flood by perhaps nearly twice as much. It could not be accurately measured, because there were no reliable marks to go by; and that extraordinary flood was calculated as the measure of the maximum discharge. He did not think any general formula could be used for all places; a formula founded on observed rainfalls and floods in one district would be useful for other districts similarly circumstanced, where the rivers had not been gauged, but in no case could observations with regard to climatic conditions be dispensed with. He agreed with Mr. Latham, that the question of the quantity of water per acre necessary for efficient irrigation was a difficult one, and had never been, and probably could not be, definitively settled; because different soils, as well as different crops, required a greater or less supply of water, according to the peculiar circumstances of the case. Rice required more water than any other crop. The result of the experiments made by the Madras Government was to fix the quantity at 2 cubic yards per hour per acre, or 66⅔ acres per cubic foot per second. That corresponded to 5,000 cubic yards per acre per crop, and was calculated to be the quantity required for rice; while more valuable crops, which would bear a higher water rate than rice, took less water to irrigate them. Colonel Smith objected to the quantity of 5,000 cubic yards per acre, and thought that at least 6,000 cubic yards should be allowed; but a few years ago, Colonel Smith, in reporting on a project of his, had assumed 3,600 cubic yards as the quantity required for the second crop, which was the one a reservoir had to supply. He mentioned this to show the quantity had not been agreed upon or calculated with certainty for different districts; but in estimating, it was necessary to take some standard; and that of the Madras Government, of 2 cubic yards per hour per acre, was what he had adopted. With respect to the objection that he had neglected the fact that half the produce of the land was taken by the Government, and therefore could not be reckoned in the receipts for land assessment; that was the principle, he believed, on which the dry lands were assessed, and he only proposed in his Paper that the same principle should be applied to wet lands. The latter, of course, yielded crops of greater value, and if half the crop were taken it would be fair to credit works, whether constructed by the Government or a company, with that amount. He did not advocate any particular agency for constructing these works—either the Government, a company, or private individuals. As commercial speculations the results would be the same whoever undertook them. His object was merely to give, as far as his information enabled him to do so, the results of such works as commercial undertakings, whether undertaken by Government or private companies. As Colonel Smith remarked, the result depended upon, first, what the water cost to get it; and, secondly, what it could be sold for. But it seemed to him that Colonel Smith abandoned the commercial view altogether, when he said a fixed rate of 12*s.* per acre must be adopted as the water rate, and not one in proportion to the cost of the works, or the value of the water to the consumer. The Madras ryots had as good an idea of the value of a rupee as any people in the world, and they were willing to pay what the water was worth, if they were allowed to do so; and they would not take the water unless they liked; but the Government said, "You shall not pay Rs. 10, although you may be willing; but you shall pay Rs. 6; and if the water cannot be supplied for Rs. 6, you shall not have it at all." Speaking of the cost of the water, Colonel Smith was mistaken in saying he had taken an imaginary average reservoir. It was a reservoir carefully surveyed and estimated, and was, out of several so estimated, the one least favourably constructed for the storage of water. It was not the favourable one proposed to be constructed by the Madras Irrigation Company—favourable with reference to the number of cubic yards of water per rupee stored. The case of the proposed restoration of the Mudduk tank was an extremely favourable one, and he had never met with any other instance where so much water was stored at so small an expense. But Colonel Smith objected to that estimate, because, he said, the supply was uncertain, and he compared it with the Maury Convai tank, of which the supply had been proved to be uncertain. Colonel Smith seemed to think these tanks were in the same neighbourhood, whereas they were nearly 100 miles apart, and the characters of the two districts were totally different. The one was on the inside slope of the Western Ghâts, and the other on the table-land of Mysore, where the rainfall was very precarious. They were no more comparable than were the Rivington Pike District and the east coast of England. The capacity of the tank was not quite equal to the maximum discharge of the river. No doubt, in that instance, it would be better if the tank were capable of containing rather more than the average discharge; but that could be effected, not at double the cost as Colonel Smith supposed, but by the usual expedient of putting in planking on the waste weir to a height of 5 feet. The rivers rising in the Ghâts fluctuated much less than those in the table-land. The usual way was to put planks between posts on the waste weir, and to take them down in case of heavy floods.

The evaporation had been calculated from observations taken in the neighbourhood, the monthly evaporation being multiplied into the mean area exposed every month. The tank was just filled at the end of the monsoon season, and the small surplus of water now discharged by the weir after that was not taken into the calculation, although it was sufficient to make up for a great part of the loss by evaporation. The tank was full only at the end of the season; then the water was gradually drawn off, and the tank was supposed to be emptied in four months. For each of these months he had estimated the quantity carried off by evaporation over the exposed area of the tank, and the total amounted to 5 per cent., instead of $6\frac{3}{4}$ per cent. as Colonel Smith calculated by a rougher method.[1] Multiplying that by the four months, Colonel Smith calculated the total evaporation to be 20 per cent. of the contents of the tank. That would bring up the evaporation to 120 inches per annum, an amount never yet registered to his knowledge. Colonel Smith had mentioned a tank in which $\frac{5}{8}$ths of the water was wasted by evaporation, and only $\frac{3}{8}$ths was put upon the land; but that tank was a very shallow one. If the tank had a depth of water of only 60 or 70 inches, with an evaporation of 30 inches, more than half would pass away by evaporation; but the case was very different in a tank 60 or 70 feet deep. Even in the dry season there was always a small stream running into the tank, which was filled by the monsoon supply alone. The loss from the canal which Colonel Smith referred to was not much, and the water quickly deposited a layer of fine mud on the bottom and sides, as happened in filtering beds. A case was known where a channel in sandy ground had to be widened, and it had been so well lined with natural puddle, that the enlargement was carried on without stopping the supply; the excavation close to the old channel was quite dry even below the level of its bed. The evaporation of the water of the canal was not ascertained, because it was included in the 2 cubic yards per hour per acre; in which, too, the evaporation in the passage of the water from the reservoir down the river to the canal was also included. He was obliged to Colonel Smith for correcting a clerical error in the statement of the cost of stored water. He had stated it, after all deductions were made, to be £1 9*s.* 5*d.*; it should have been £1 13*s.* 8*d.*, in the least favourable case he had estimated. The bed of the river was rocky, with here and there layers of sand left by the floods; lower down, about Kurnool, there was more sand. Even after the streams ceased running, the drainage of the country into the river, which was the main drain of a very large district, was more than sufficient to make up for the loss by evaporation. It had been gauged in the hot weather, and the discharge was found to be less in the upper than in the lower part; in 1868 it was only one-eighth. This differed from Mr. Jacob's experience in the Bombay Presidency, where he found that though a good deal of water flowed in, the evaporation made up for it, and the river discharge at the lower end was more than it was at the upper end. The objection that the reservoir did not hold the whole supply did not apply to the other reservoirs estimated for, which were more favourably situated; because, there the difficulty was not how to fill the reservoirs, but how to get rid of the surplus water. The largest reservoirs he found took little more than half the monsoon supply of the river; and then the water required to be embanked, to prevent it running over a watershed into another river. The difficulty was to get sites where the floods could be impounded. The Mudduk Masoor tank was capable of impounding the whole flood water. He could not accept Colonel Smith's conclusions, that only half the water stored was used on the fields. Colonel Smith gave no figures in support of that conclusion; and he believed 15 per cent. would be the full amount of waste, assuming the Government rate of supply of 2 cubic yards of water per hour per acre in the main canal.

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[1] The months March and April, when the evaporation was greatest, were those when the area of water in the tank was least.

Mr. Aitken had stated that canals which cost only Rs. 7,000 per mile gave returns of from 40 to 60 per cent., and that, therefore, others costing Rs. 70,000 would yield only 4 to 6 per cent.; but the quantity of water carried must be reckoned, not the cost per mile. He admitted that the different measures used, viz., the cubic yard per hour in Madras, and the cubic foot per second in Bengal, and in some cases gallons, were very inconvenient; but the difficulty would not be remedied by the introduction of a fourth measure, the cubic metre. He thought the reckoning by cubic feet per second was the most handy.

From time immemorial it had been the custom to dispense with puddle in native works, and in the parts of India he was best acquainted with, there was no clay to make puddle with; in fact, there was a district 250 miles long and 100 miles broad where no stiff clay was to be found. There was at first a little leakage in a new bank, but it soon got puddled by the deposit from the muddy water, the banks became impervious, and this was effected by the silt existing in the river. In some cases the slope of the reservoir banks was protected by large stones built in the form of steps, and in others they were laid on the flatter slopes. Breaches often occurred in small tanks; they were generally repaired by forming a ring-dam in front, and sometimes the bank was cut to relieve the pressure of the water. That was done, when it was possible to do it, where the bank was on rocky ground, so as to cause as little damage as possible.

A great part of the water was evaporated after it was turned on the fields. The evaporation in places exposed to the hot winds was $\frac{1}{3}$ of an inch per day, and a crop of rice was under water about a hundred days; so that about 33 inches would pass away by evaporation, which left only 5 or 6 inches to be disposed of by infiltration and drainage. The evaporation was perhaps reduced in the last months of the crop, by the water being sheltered by the grain, and, he believed, might amount to 30 inches altogether.

In experiments made by Colonel Meadows Taylor on the wells of the Deccan, it was found that 6,000 cubic yards was the quantity per acre used for the two crops of the year. The first crop consisted of turmeric, chillies, ginger, plantains, and other valuable garden produce; the second crop was wheat or cereals. For those two crops rather less than 6,000 cubic yards of water per acre were sufficient, and in the use of wells there was very little water wasted, as the water was raised at a cost to the ryots of Rs. 27½ per acre, exclusive of interest upon the cost of the wells.

The reservoir mentioned by Mr. Conybeare was a comparatively small one, and he agreed that a small quantity of water could not be stored economically in India for the purposes of rice irrigation.

As to the revenue to be derived from irrigation works, if the Government fixed the rate so low that it was not remunerative, it was likely to give them a bad name. It was said they were not constructed because they were not remunerative; but they were not so only because the Government would not allow a charge which the people were ready to pay.

He thought the plan adopted by Colonel Dyas for breaking the force of the water in the falls of the Baree Doab canals an admirable one. The effect of the gratings was to break up the falling water and distribute it over a larger area, but he thought the plan was less applicable to weirs in rivers, to which the remarks about water cushions in the Paper referred, as all the length that could be got for a clear overfall was needed, and the introduction of gratings would require a greater length, or else the level of the water must be inconveniently raised. He thought them excellent for canal falls, and they seemed to have answered their purpose perfectly. The well irrigation, which seemed to please the people in the part of India described by Major Browne, would never be extensively practised in the South. In the Deccan, 4½, and in Bellary, 3 acres, were the most one well would irrigate; the water was slightly brackish generally, and the cost of raising it by the cheapest method, if animal power was employed, was too high—55*s.* per acre in the Deccan, probably 80*s.* in Bellary, and 60*s.* at the experimental farm at Sydapett, Madras.

Mr. A. A. West supplied, through the Secretary, a table of the evaporation at Bombay, during the dry season, from a surface of 100 square inches of water in a cistern, open to the air, but shaded from sunshine:

		Days.	Inches.		Inch.	
1814	October	31	4·80	Average	·155	a day.
,,	November	30	4·60	,,	·153	,,
,,	December	31	4·45	,,	·143	,,
1815	January	31	4·15	,,	·134	,,
,,	February	28	3·85	,,	·137	,,
,,	March	31	4·65	,,	·155	,,
,,	April	30	5·55	,,	·185	,,
,,	May	31	5·30	,,	·174	,,
	Total	243	37·35	,,	·154	,,

The rains of 1814 ended on the 14th of October. Those of 1815 began on the 5th of June. The greatest evaporation in a day was 0·20 inch in the middle of April and latter part of May. The least was 0·12 inch in December and early in January.

During the month of May the thermometer varied from 90° to 102° Fahr. in the open air shaded from the sun; and from 87° to 90° in the house from 8 A.M. to 11 P.M.

The evaporation at Bombay during the rainy season, under the same conditions as the preceding, was:

		Days.	Inches.		Inch.	
1815	June	30	3·05	Average	·102	a day.
,,	July	31	3·10	,,	·100	,,
,,	August	31	4·60	,,	·148	,,
,,	September	30	4·45	,,	·148	,,
	Total	122	15·20	,,	·124	,,

The rains of 1815 began on the 5th of June, and ended on the 16th of October. The evaporation in August was high; it was 2·35 inches in 1814, and 2·45 inches in 1816. The greatest evaporation in a day was 0·18 inch in clear weather in July and August, and 0·19 inch in October. On wet days it was 0·10 inch. The least was 0·05 inch during continual rains in June and July.

Mr. F. D. CAMPBELL said he did not agree with the Author as to the financial results of irrigation works in India, taking the country as a whole. The cases he gave were correct, but they had only to do with small works, which had been undertaken, and put in repair because of their peculiar advantages. The large and altogether new works now being constructed in Madras had very different prospects before them, as he knew from what he heard officially when he visited them three years ago. Excepting in the case of delta irrigation, there were no large works of the storage class, which had been working for some time, from which to draw any practical conclusions. He believed that the best works now being made would not yield more than 5 per cent., and they might be expected to do so about ten years after completion.

February 6, 1872.

THOMAS E. HARRISON, Vice-President, in the Chair.

The following Candidates were balloted for and duly elected:—Howard Aston Allport, William Barrington, John Elliott, William John Galwey, George Henry Hill, George Robert Jebb, Alexander McDonnell, M.A., and Daniel Pryce, as Members; John Walker Balmain, James William Butler, Samuel Carrington, Henry Chapman, John Cleghorn, Alfred Dowson, Whately Eliot, Richard Hammersley Heenan, Colonel James Macnaghten Hogg, M.P., Elihu Henry Oliver, Henry Blackburn Parry, Frederick Molesworth Pfeil, John Phillips, Gilbert Richard Redgrave, Henry Francis Ross, Albert Marcius Silber, Charles Tomlison, Henry Tomlison, George William Usill, Stud. Inst. C.E., Rienzi Giesman Walton, George Herbert West, and William Henry White, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. VIII., of the Bye-Laws, had transferred Horace Bell and Thomas Codrington from the class of Associate to that of Member.

Also, that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—Frederick George Banister, Edward Ernest Brice, Alfred Edward Carey, Griffith Nathaniel Cox, Martin William Browne Ffolkes, Edgar Giberne, John Hunter Jones, and William Beswick Myers.

The discussion upon the Paper, No. 1,318, "On the Value of Water, &c.," by Mr. G. Gordon, was continued throughout the meeting.

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